ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

First Partial Report

On

PROJECT NO. T-5 - TEST OF FLAMEPROOFED CLOTHING

SUBJECT: PHYSIOLOGIC EFFECTS OF WEARING FLAME-PROOFED CLOTHING IN HOT ENVIRONMENTS

Project No. T-5

17 July 1945

Serial

U.S. Armored medical research laboratory,
Fort Knox, Ky.
Project no. T-5

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. T-5
File SPMEA 727-2

17 July 1945

1. PROJECT: NO. T-5 - Test of Flameproofed Clothing, First Partial Report.
Subject: Physiologic Effects of Wearing Flameproofed Clothing in Hot Environments.

a. Authority: Letter, 6th Indorsement, SPMDO 421, ASF, SGO, Washington, 25, D. C., 7 December 1944.

b. Purpose: To determine the physiologic effects from wearing flameproofed garments in hot environments, with particular reference to the heat load imposed.

2. DISCUSSION:

Protection of personnel against fire has always been a problem in armored vehicles. A high proportion of the tanks knocked out in combat burn, and the incidence of burns to total casualties is disproportionately higher in tank crews than in other combat arms. The increasing use of flame as an offensive weapon by ground troops emphasizes the necessity of adequate protection of personnel against fire. As one of the means of protection, flameproofed clothing has been developed. However, the impregnation of clothing with flame resisting substances raises new problems apart from the actual flame resistance of the garments.

It was the purpose of this investigation to study some of these new problems, principally those dealing with (1) the heat load imposed by the clothing, (2) the general acceptability of the clothing from the standpoint of its flexibility, porosity and comfort, and (3) possible toxic effects from the impregnite, both locally in the form of skin rashes and systemically in whatever manner they might be manifested. Of these, the question of the heat load of the clothing is particularly important to the Armored Command because in hot climates closed armored vehicles may develop internal environments which are more severe than any naturally occurring climate. Such conditions impose severe stresses on the crew, making additional thermal loads undesirable.

The garments were prepared by the Technical Division of Chemical Warfare Service. The impregnating formula of the flameproofed clothing here studied was chlorinated paraffin/CC-2/zinc oxide/aluminum stearate/acetylene tetrachloride in the following amounts by weight 139/139/139/17/1623. These garments were labelled "D". The initial pick-up was 47% of the original garment weight. As this was considered to be excessive, it was reduced to 38% by one laundering prior to shipment for test. The impregnite was designed to protect against both fire and chemical warfare agents. Garments impregnated with compounds to protect against flame alone were not available. For comparison, the men worked nude or in herringbone twill.

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. T-5
File ARMRL 727-2 17 July 1943

1. PROJECT: No. T-5 - Test of Flame-proofed Clothing, First Partial Report. Subject: Physiologic Effects of Wearing Flameproofed Clothing in Hot Environments.

a. Authority: Letter, CG [illegible], SPMDD [illegible], AGF, 400, Washington 25, D. C., 9 December 1942.

b. Purpose: To determine the physiologic effects from wearing flame-proofed garments in hot environments, with particular reference to the heat load imposed.

2. DISCUSSION:

Protection of personnel against fire has always been a problem in armored warfare. A large proportion of the tanks knocked out in combat burn, and the incidence of burns in total casualties is disproportionately higher in tank crews than in other combat arms. The increasing use of flame as an offensive weapon by ground troops emphasizes the necessity of adequate protection of personnel against fire. As one of the means of protection, flameproofed clothing has been developed. However, the impregnation of clothing with flame resisting substances raises new problems apart from the actual flame resistance of the garments.

It was the purpose of this investigation to study some of these new problems, principally those dealing with (1) the heat load imposed by the clothing, (2) the general acceptability of the clothing from the standpoint of its flexibility, porosity and comfort, and (3) possible toxic effects from the impregnation, both locally in the form of skin rashes and systemically in whatever manner they might be manifested. Of these, the question of the heat load of the clothing is particularly important to the Armored Command because in hot climates armored vehicles may develop internal environments which are more severe than any naturally occurring climate. Such conditions impose severe stresses on the crews, making additional thermal loads undesirable.

The garments were prepared by the Technical Division of Chemical Warfare Service. The impregnating formula of the flameproofed clothing [illegible] and [illegible] [illegible] [illegible] in the following amounts by weight [illegible]. These garments were laundered [illegible]. The initial pick-up was [illegible]% of the original garment weight. As this was considered to be excessive, it was reduced to [illegible]% by one laundering prior to shipment for test. The impregnite was designed to protect against both fire and chemical warfare agents. Garments impregnated with compounds to protect against flame alone were not available. For comparison, the same garment made up in herringbone twill.

It has been assumed that adequate fire resisting qualities had been imparted to the test clothing and that these qualities were retained throughout this study. Representative garments have been submitted to proper agencies for flame resistance tests.*

In the design of these experiments, three categories of hot environments were chosen:

a. Naturally occurring climates

(1) Hot temperate - D.B. 100°F, W.B. 90°F.
(2) Hot humid (tropical) - D.B. 90°F, W.B. 88°F.

b. Severe conditions which may occur within tanks
D.B. 120°F, W.B. 80°F to 90°F.

c. The upper environmental limits at which men can work:

(1) Saturated conditions D.B. 95°F, W.B. 94°F.
(2) Hot dry conditions D.B. 120°F, W.B. 92°F.

The test period consisted of four (4) hours of continuous work requiring the expenditure of approximately 250 Cals/hour, equal to the energy expenditure of a tank driver during rough cross country driving.

3. **CONCLUSIONS:**

a. In hot environments simulating severe naturally occurring hot temperate (D.B. 100°F, W.B. 80°F, relative humidity 43%) and hot humid (tropical, D.B. 90°F, W.B. 88°F, relative humidity 92%) climates:

(1) Well acclimatized men are capable of working effectively, without disability and with equal efficiency whether they wear regulation herringbone twill or flameproofed "D" garments.

(2) In comparison with the nude state, this clothing imposes only a slight heat load and two layers of clothing, with or without hood and gloves, are tolerated easily and almost as well as one layer of clothing.

b. In hot environments simulating those found within tanks (D.B. 120°F, W.B. 88° to 90°F, relative humidity 30%) operating in hot climates:

(1) Clothing imposes definite and considerable heat loads. In the performance of a given amount of work, clothed men exhibit greater physiologic changes than nude men.

* N.R.C. Project Q.M.C. No. 27, Preliminary Report Sub-project 27-A5-X-2, dated 30 April 1945.

(2) Fit, well acclimatized men are still capable of working effectively and without disability when clothed in single layer herringbone twill or single layer flameproofed "D" garments.

(3) For a given amount of work, greater physiologic changes are induced in men wearing single layer flameproofed "D" clothing than in men clothed in single layer herringbone twill garments.

c. At the upper limits of hot environments in which men can work (D.B. 95°F, W.B. 94°F, relative humidity 96%; and D.B. 120°F, W.B. 92°F, relative humidity 35%):

(1) Clothing now imposes a critical heat load which decreases the ability of men to work. It lowers the limiting wet bulb temperature of the upper environmental limits by from 2°F to 4°F.

(2) In this regard, single layer flameproofed "D" clothing has a greater and more deleterious effect than single layer herringbone twill.

(3) The effect of clothing (single layer) on the limiting wet bulb temperature of the upper limits at which men can work for four (4) hours is summarized in the following table.

	Limiting Wet Bulb Saturated Environments		Limiting Wet Bulb Environments with D.B. 120°F.	
	Difficult	Impossible	Difficult	Impossible
Nude	94	96*	92	94*
Single Layer Herringbone Twill	92	94	90	92
Single Layer Flameproofed "D" Twill	92	94	88	90

* Established in a previous study.

d. The principal differences between the herringbone twill and flameproofed "D" garments are:

(1) With wear, herringbone twill rapidly becomes pliable. The flameproofed "D" clothing remains rather stiff, hard, coarse and is physically irritating to the skin.

(2) Herringbone twill readily absorbs water while the flameproofed "D" garments appear to be relatively water repellent.

(3) The physical gradient for evaporation (volume sweat evaporated per square meter of surface area per mm Hg difference in water vapor pressure at the temperature of the skin and the environment) through flameproofed "D" clothing in the erect subject was found to be roughly two-thirds of the gradient through herringbone twill.

e. The flameproofed "D" clothing did not produce toxic changes of either a local or systemic nature.

f. Healthy, fit, well acclimatized men can work effectively in hot surroundings when wearing flameproofed "D" clothing. At the extreme upper limits of heat, the wearing of impregnated clothing induces greater stresses than the wearing of ordinary herringbone twill fatigues.

4. RECOMMENDATIONS:

a. That the material of this report be distributed to agencies concerned in the development of formulae and ultimate use of clothing designed to protect against fire and chemical warfare agents.

b. That these agencies continue to consider, along the lines developed in this report, not only the protective qualities of such clothing but all of the new problems which arise in the ultimate wearer.

Submitted by:
Ludwig W. Eichna, Major, MC
Steven M. Horvath, Major, SnC
Walter B. Shelley, Captain, MC

Assisted by:
Howard Golden, Tec 3
John E. Wagar, Tec 3
Kenneth C. Davis, Tec 3
James P. Stack, Tec 3
William J. Robinson, Tec 5
James W. Gregg, P-4

APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps
Commanding

4 Incls.
#1 - Appendix with Tables 1 and 2
#2 - Tables 3 thru 17
#3 - Charts 1 thru 12
#4 - Photographs 1 and 2

APPENDIX

A. SUBJECTS, EXPERIMENTAL CONDITIONS AND PROCEDURES

This investigation was conducted in the same general manner as a previously reported study.* All observations were made in the laboratory hot room during January, February and March, 1945.

1. Subjects

Their ages ranged from 20 years to 24 years (average 21.3 years). Their weights varied from 140 pounds to 178 pounds (average 156 pounds); their heights from 64 inches to 72 inches (average 69 inches); their surface areas from 1.7 square meters to 2.0 square meters (average 1.89 square meters). They were all normal, healthy and physically fit.

2. Environments

The studies were carried out in three (3) types of environments.

a. Environments simulating severe naturally occurring climates both hot temperate and hot humid (tropical).

b. Environments comparable to those within tanks operating in hot climates.

c. Environments at the upper limits tolerated by working men. The characteristics of the environments studied are detailed in Table 1.

TABLE 1

ENVIRONMENTS IN WHICH HEAT LOAD OF CLOTHING WAS STUDIED

TYPE OF ENVIRONMENT		Dry Bulb Temp. °F	Wet Bulb Temp. °F	Relative Humidity %
A. Severe, naturally occurring climates	Hot temperate	100	80	41
	Very hot temperate	100	86	57
	Hot humid (tropical)	90	88	92
B. Conditions within tanks in hot environments		120	88	28
C. Upper Environmental limits	Hot, relatively dry	120	90	31
		120	92	35
	Hot Humid	93	92	95
	Almost saturated	95	94	96

* Project 2, Sub-project 2-11, 2-13, 2-17, Subj., The Upper Limits of Environmental Heat and Humidity Tolerated by Acclimatized, Normal, Young Men Working in Hot Environments, dated 2 October 1944.

Incl. #1

Throughout the tests, the dry and wet bulb temperatures, measured with a motor driven psychrometer, carried around the track 3 times, at a level of four (4) feet usually did not vary from the desired temperatures by more than 1°F. These were recorded every fifteen (15) minutes. The walls and floor were brought into equilibrium with the air temperature, by initiating the desired conditions in the hot room 12 to 15 hours before the men began to work. Wall and floor temperatures were not measured and are assumed to be the same as those previously determined under similar conditions; i.e., walls 2°F to 5°F cooler than the air and the floor 10°F cooler at dry bulb temperatures under 100°F but 20°F cooler at dry bulb temperatures of 120°F. Additional radiant heat was not supplied. Dry bulb air temperatures showed a gradient of 4 to 5° from floor level to the six foot level.

A mildly turbulent air movement in all parts of the room resulted from the combination of hot air inflow from four anemostats in the ceiling and four (4) sixteen (16") inch fans placed on the floor at the four corners of a wind tunnel in the middle of the room. The fans were directed toward the floor. Wind velocity was not measured but was essentially that produced by the movement of the men marching at 3 mph.

3. Activity

The standard work consisted of walking, in single file, at 3 miles per hour around a 77 foot track in the hot room. The men carried 20 pound packs, were started at 4 minute intervals and walked simultaneously. This work rate was previously determined to be approximately 250 Calories per hour. Four (4) hours of such continuous marching without rest and without leaving the hot environment constituted the standard daily work requirement. At hourly intervals during work, each man halted and stood erect for 2 to 3 minutes while the hourly check data (heart rate and rectal temperature) were obtained. Observations were also made during an hour of quiet sitting in the afternoon.

A standard day consisted of 8 to 9 hours spent in the hot environment: 0745 hours to 1230 hours, walking period; 1300 hours to 1400 hours, lunch; 1400 hours to 1600 hours, sitting period. When only one or two hours of walking were accomplished in the morning, walking was substituted for the afternoon sitting period. After 1600 hours, the men returned to their own quarters on the post and reported at the Laboratory the next morning.

For one week, the men performed the standard work requirement under normal cool indoor conditions. This toughened the feet, accustomed the men to the work and experimental procedures and tended to produce a more uniform state of physical fitness in all men. Then followed an acclimatization period of 10 days during which the men worked in an environment of D.B. 120°F*, W.B. 88°F*, R.H. 28%.* After these two preliminary training periods, the definitive study of the heat loads of the clothing was begun.

Thereafter each time that the environmental conditions were changed, the men were acclimatized to the new environment over a period of three or four days before the test runs were undertaken. However, in the environment D.B. 120°F, W.B. 90°F,

* Henceforth D.B. will designate dry bulb temperature, W.B. wet bulb temperature and R.H. relative humidity.

Incl. #1

it was necessary to shorten this period to one day. Previous studies have shown the need for acclimatization to each new environment regardless of full acclimatization in previous environments. Only subjects fully acclimatized to the given environment behave in such a repetitive fashion that they can serve as standardized test subjects for the determination of added loads. In the milder environments which do not impose a considerable heat load, prolonged acclimatization is not necessary. Since the data in this report are for subjects fully acclimatized to each environment, the reactions of the men to the clothing heat load are minimized. It was found that in unacclimatized subjects, clothing induced greater physiologic changes.

4. Food and Water

The men ate field rations, type A, obtained from the company mess. Only the mid-day meal was eaten in the hot environment. The amount of food eaten was not measured but generally the men ate heartily.

All drinking water was made up as a 0.1% solution of sodium chloride and maintained at a temperature of 35°C. The amount drunk was carefully measured. The water intake approximated the sweat loss except in some men in the most severe environments. After leaving the hot room, the men drank tap water.

5. Clothing

The following types and assemblies of clothing were worn during this study:

	Shoes* Service	Socks* Half Wool	Shorts* Cotton	Drawers Cotton	Under-shirt Cotton	Jacket	Trousers	Hood	Gloves
Nude	X	X							
Herringbone Twill Single Layer	X	X	X			X	X		
Flameproof Twill Single Layer	X	X	X			X	X		
Herringbone Twill Double Layer	X	X		X	X	X	X		
Flameproof Twill Double Layer	X	X		X	X	X	X		
Flameproof Twill Complete Assemb.	X	X		X	X	X	X	X	X

* These garments were untreated.

All flameprocfed "D" clothing was impregnated with the formula: chlorinated paraffin CC-2/zinc oxide/aluminum stearate/acetylene tetrachloride in the following proportions by weight 139/139/139/17/1623. The impregnation renders the garment both flameproof and gasproof. The amount of impregnite picked up by each article expressed as a percentage of its initial weight was as follows: hood, 43%; gloves, 43%; long undershirt, 43%; long drawers, 43%; jacket, 47%; trousers, 47%. The 47% pick-up by the

Incl. #1

jacket and trousers was considered excessive and was reduced to 38% by one laundering prior to shipment of the clothing to this laboratory.

Each subject was issued clothing of the best possible fit from the limited stocks and always wore his own clothing in all tests. Each subject's two piece herring-bone twill fatigue uniform and two piece flameproofed fatigue uniform were of the same size. The clothing was always worn in the same manner; trouser legs tucked inside of the pulled up socks, jacket shirt tucked into the waist of the trousers, top button of jacket buttoned and sleeves unbuttoned at the wrists. This method of wear was chosen as offering the greatest protection against flame. Since it reduces the bellows action of the clothing, these tests were carried out with the clothing imposing their maximum heat loads.

6. Observations and Data Obtained

Upon arrival in the morning, the men remained in the control (70-75°F.) room until individually called into the hot room approximately 7 to 10 minutes before be-ginning to walk. Each man entered the hot room completely nude, urinated, dried off any sweat present and was weighed (within 10 grams). Simultaneously the individual items of clothing he was to wear (placed in the hot room 30 to 45 minutes earlier) were also weighed (within 5 grams). The subject quickly dressed in these garments, and stood erect 4 minutes during which the heart rate*, rectal temperature and skin temperature radiometrically (5 areas) were determined simultaneously. He then began marching. During the walking period all water drunk, urine voided and vomitus were carefully measured. At hourly intervals, the heart rate and rectal temperature were determined. After 4 hours of walking, the subject stood erect while the heart rate, rectal temperature and skin temperature were measured. He then stripped completely, urinated, dried off all of the sweat and was weighed. At the same time, his removed clothing was weighed, item by item. Throughout the entire test, records were kept of symptoms, complaints, general appearances, vigor and alertness of the men.

The skin temperature of 5 areas of the body, three covered and two uncovered (chest, forearm, calf, cheek, palm) were determined with a radiometer. For clothed areas, the clothing was opened or pushed aside just sufficiently to permit placing of the radiometer. Undue exposure of clothed areas was avoided. The skin temperatures of individual areas were integrated into an average skin temperature by the following weighting formula based on the original formula of Hardy: chest, 0.44; forearm, 0.14; calf, 0.23; cheek, 0.10; palm, 0.09. Henceforth the term skin temperature will refer to this weighted average skin temperature. Rectal temperatures were measured with calibrated rectal thermometers.

Whenever a man was forced to discontinue walking before the required four hours, the final observations were taken and the time recorded. No man was allowed to discontinue unless objective indications necessitated it.

7. Charting

The charts numbered 1, 2, 3, 4, 5, 8, 9, 10 and 11 indicate the physiologic

* All other heart rates were determined on the men marking time during the first half minute following their removal from the track.

Incl. #1

responses of the men in various environments. Corresponding tables give the individual data so that the range and variability of individual response may be more fully appreciated after examining the principles of group behavior presented on the graphs.

B. RESULTS

1. General Consideration

The principles governing the analysis of the data of this study are those which have been developed and reported in detail in previous studies of men in the heat. Briefly, these are: (1) Unacclimatized men improve greatly in their responses to heat from day to day. Only fully acclimatized men have sufficiently constant responses to heat to serve as standardized test subjects for the evaluation of added factors and loads in the heat. Using such test subjects, the effect of added loads will always be presented in the most favorable light. Unacclimatized men subjected to the same loads will have poorer performances. (2) The man as a whole must be considered and evaluated with proper weight given to phenomena which cannot be represented by a number. Appearance, behavior, complaints, vigor, alertness, morale and performance must be given due weight. This weighting depends on the experience of the observer. It may equal or even exceed the weight given to such numerically representable physiologic data as rectal temperature, heart rate, sweating rate, skin temperature. (3) Since the physiologic data can be represented numerically and graphically, most of the following analysis is in these terms. It is to be understood that these serve as gross indices and are valid only when they are consistent and representative of the picture in the man as a whole. The data here presented are to be considered so consistent. (4) Individual subjects exposed to similar heat stresses vary considerably in their responses. Therefore, the averaged data for a group has been graphed while individual data appears in tables.

The subjects were divided into two groups of five (5) men each. These two groups (henceforth designated A and B) were made as comparable as possible on the basis of age, physical characteristics and physiologic responses to work in the heat.

TABLE 2

PHYSICAL CHARACTERISTICS OF THE TWO TEST GROUPS

GROUP	NAME	AGE	WEIGHT Pounds	HEIGHT Inches	SURFACE AREA Sq. Meters
A	DIM	21	140	68	1.75
	SZU	23	144	69	1.80
	MAR	20	153	70	1.86
	LIN	20	169	72	1.99
	KNE	20	168	72	1.99
	AVG	21	155	70	1.88
B	LOW	20	141	64	1.69
	MIC	20	145	69	1.80
	HIL	24	150	67	1.78
	KAC	24	171	71	1.97
	SCO	21	178	71	2.02
	AVG	22	157	68	1.85

Incl #1

Additional data on the comparability of the two groups in each environment was always established by the day of working nude. This day also afforded a base line of response with which the performance in the two types of clothing could be compared.

2. Heat Load - Single and Double Layer Clothing Assemblies; Environments Simulating Naturally Occurring Hot Climates.

a. Hot Temperate Climates - D.B. 100°F, W.B. 80°F, R.H. 92%

Although the men complained that the single layer flameproofed clothing was "hotter" and provided less ventilation than the single layer herringbone twill, the thermal stress imposed by these environments was of such a low order of magnitude that the physiologic changes induced in the men were slight regardless of what they wore. This is indicated by the observations made on a group of four (4) men working in an environment of D.B. 100°F, W.B. 80°F, R.H. 42% on one occasion nude, on another in single layer flameproofed clothing, on a third in double layer flameproofed clothing and finally in the full flameproofed assembly (Chart 1 and Table 3). It is apparent that the addition of clothing induced very few physiologic changes; the performance, rectal temperature and heart rates remained practically identical. The final skin temperature did not fall to as great an extent when additional layers of clothing were worn. The values were still within a normal range. The sweating rate increased progressively as clothing was added and in the full impregnated assembly it was double that in the nude. This is of significance from the standpoint of troop water requirements.

In the absence of sufficient thermal stress differences, the potential heat loads of clothing do not become apparent unless they are very marked.

Men worked in both the two layer herringbone twill and the two layer flameproofed assemblies with equal ease and Chart 2 and Table 4 indicates that the physiologic changes induced by the two types of clothing were minimal and practically identical. Moreover, insofar as the heart rate and rectal temperature are concerned, the physiologic changes in the clothed and nude men were essentially the same. The clothed man exhibited an average sweat rate 100% above the nude. There was no fall in skin temperature such as occurred in the nude men.

b. Very Hot Temperate Climate - D.B. 100°F, W.B. 86°F, R.H. 57%

This environment differed from the previous one by an increased humidity. The men worked in this environment for one day only; one group in two layer herringbone twill, the other in two layer flameproofed assembly. Chart 3, Table 5 indicates that the physiologic responses of the two groups were very similar. In all measurements, however, the response of the group wearing flameproofed clothing was insignificantly greater than that for the group wearing herringbone twill. With large numbers of men, these differences would have probably been statistically significant. There was, however, one striking difference in the two groups. One man wearing flameproofed clothing was completely exhausted at the end of two hours and was forced to drop out. Indeed, his rapid heart rate of 171 per minute is largely responsible for the difference in the two curves of heart rate. The poor performance and exaggerated physiologic responses of this one subject in the presence of the relatively good responses of his colleagues is not explained.

Incl. #1

c. Hot, Humid (Tropical) Climate - D.B. 90°F, W.B. 88°F, R.H. 93%

This almost saturated environment is equivalent to that found under severe jungle conditions. Here again the men worked for one day only, half of the group wearing two layer herringbone twill and the other half wearing two layer flameproofed assemblies. The clothing imposed no handicap to effective work, the physiologic responses in the two groups of men being almost identical (Chart 4 and Table 6). The pulse rate and final skin temperatures in men wearing the flameproofed assembly are in agreement with the previous indications of the greater load of this assembly.

SUMMARY

The studies in these environments have not demonstrated any real differences in the heat load imposed by the flameproofed and herringbone twill clothing. These experiments indicate that clothed men can work effectively in severe naturally occurring environments.

3. Heat Load - Single Layer Clothing Assemblies

a. Environments Simulating Those Within Tanks in Hot Climates - D.B. 120°F, W.B. 88°F, R.H. 28%

This environment is representative of the extreme of conditions found in the driving compartments of buttoned-up M4A3 tanks operating in midday in midsummer at Camp Polk, La. It imposes a marked thermal stress which can be tolerated only after considerable acclimatization. Because of the severity of this stress, the studies in this environment were limited to the heat loads imposed by single layer assemblies of clothing. Under these conditions, differences in various types of clothing were demonstrated.

Chart 5 and Table 7 show that well acclimatized, fit men can, both nude and clothed, work effectively for at least four (4) hours in such an environment. However, the "cost," measured in terms of the severity of the physiologic responses was greater for clothed men than for nude men. Except for a material increase in the sweating rate, the physiologic changes when wearing herringbone twill were only slightly greater than when the men were nude. When the men wore flameproofed clothing, the physiologic changes were greater. The elevated rectal and skin temperatures were indications that the clothing offered a considerable barrier to the dissipation of heat. However, the sweating rates were identical whether herringbone twill or flameproofed twill was worn. At D.B. 120°F, W.B. 88°F, the heat load of the herringbone twill clothing is still easily tolerated but the load imposed by the flameproofed clothing begins to approach undesirable proportions.

b. Environments at the Upper Limits Tolerated by Working Men

(1) D.B. 120°F, W.B. 90°F, R.H. 31%
(2) D.B. 120°F, W.B. 92°F, R.H. 35%
(3) D.B. 93°F, W.B. 92°F, R.H. 97%
(4) D.B. 95°F, W.B. 94°F, R.H. 97%

The criteria for the upper environmental limits for work in the heat utilized in this study were described in detail in a previous report and are briefly restated. Environments are considered "relatively easy" when all men finish the required four (4) hours of work in good spirits, without difficulty or complaints

Incl. #1

and with physiologic changes no greater than those seen in acclimatized men working in typically desert or tropical heat; i.e., group average rectal temperatures under 101°F and group average heart rates less than 130 beats per minute. Environments are considered "difficult" when all men still finish the required four (4) hours of work but now with much effort, many complaints, lack of alertness, approaching exhaustion and with physiologic changes exceeding in severity those usually encountered in acclimatized men working in hot climates; i.e., group average rectal temperatures between 101°F and 102°F and heart rates between 130 and 145 beats per minute. Occasionally one man may fail to finish. Environments are considered "impossible" when the group as a whole fails to finish the required four (4) hours of walking. The men suffer from many distressing and severe symptoms and many fall out during the second hour of effort. Few are capable of finishing the four (4) hours of work. The group average rectal temperature exceeds 102°F, and the group average heart rate averages 150 beats per minute. Critical judgment must be employed with these "rules of thumb" and attention must be given to the over-all picture without focussing on other factors; e.g., physiologic responses. Since these "rules of thumb" are based on group phenomena, they can never be used to predict individual performance.

The "second-wind" improvement discussed in the previous report was again encountered. This subjective improvement usually occurred late in the second or early in the third hour of work and was again associated with the approach of an equilibrium state. In the clothed men, it also seemed to be associated with the wetting of the clothing with sweat. As the garments became progressively wetter, the men remarked that they felt "cooler" and they worked more easily.

The present experiments were designed only to bracket the upper limits and delineate the least severe environments in which the men could not work and the most severe environments in which they could work. Only environments of two extreme types were studied; i.e.,

(a) A humid atmosphere with D.B. 93 - 95°F.
(b) A relatively dry atmosphere with a D.B. of 120°F.

The environments were kept as close to the limit as possible and no work was done to define the "relatively easy" environments. Neither was work done to re-study the upper limits for the nude men. The environments were always picked with regard to the clothed state. "Impossible" in this report is equivalent to the "impossible" in the previously reported study and upper limit in this report to "difficult" in the previous study.

Charts 6 and 7 indicate the effect of the two types of clothing on the upper environmental limits at which men can work. Clothing lowered the upper limit to the extent of reducing the limiting wet bulb temperature of the environment by 2°F to 4°F. This reduction occurred at both the "upper limit" (Chart 6) and the "impossible" levels (Chart 7). Wearing herringbone twill lowered the limiting wet bulb temperature by 2°F for both the saturated and the hotter drier environments. However, when wearing flameproofed clothing, the limiting wet bulb temperature was lowered by 2°F for saturated environments and by 4°F for environments with a D.B. 120°F. This is consistent with the greater barrier to evaporation imposed by the flameproofed clothing and hence its greater heat load in environments where evaporation is the sole means of losing heat and maintaining thermal equilibrium. Its heat load is not as great where evaporation is not as significant an avenue of heat loss (saturated environments).

Incl. #1

Analyses of the performances and physiologic responses of the men in these "upper limits" environments in the nude, wearing herringbone twill or flameproofed clothing are presented in Charts 8, 9, 10 and 11 and in Tables 8, 9, 10 and 11. A uniformity of response along a definite pattern is apparent. When clothed in flameproofed garments, the overall response is always the poorest and when nude the response is the best; wearing herringbone twill gives an intermediate response.

Increasing the wet bulb temperature from 88°F to 90°F when the dry bulb was 120°F served to separate the two clothing issues more clearly from the standpoint of their respective heat loads. Men clothed in herringbone twill were all able to complete four (4) hours of work whereas half of the men in flameproofed clothing dropped out (compare Chart 5 and 8). When the thermal stress of the surroundings became very marked (D.B. 120°F, W.B. 92°F and D.B. 95°F, W.B. 94°F) this stress was in itself so great that men with both types of clothing were quickly forced to fall out and a determination of the added loads of the two garments became difficult as their individual loads were submerged in the greater environmental load (Charts 9, 11).

4. Physical Characteristics of the Clothing

a. Gross Characteristics

The flameproofed twill garments were heavy, thick, stiff, coarse, rough and waxy. The men objected mildly to these characteristics. With repeated wear, the cloth became more pliable and less coarse but never as soft and flexible as herringbone twill. Its weight remained constant throughout the study indicating that the impregnite had not leached out (Table 12).

The flameproofed clothing was resistant to wetting. (Photograph 1) The garments appeared wettest where the clothing came into direct contact with skin (shoulders, upper back, anterior surface of the thighs). Unless rubbed directly into the cloth, the sweat tended to roll on the clothing like "water on a duck's back," (Figure 1). As a consequence, the sweat was funnelled along the inner surface of the clothing, dripping out of the sleeves and running into the socks and out of the shoes. With repeated wearing, the flameproofed garments wetted to a greater degree than on initial wear, but even so the wetting was not uniform and did not approach the water uptake of herringbone twill (Figure 12, Photograph 2).

b. Absorption of Water

(1) Uptake of Sweat During Walk

The reduced capacity of flameproofed clothing to absorb water was quantitatively demonstrated. After having been dried for at least fourteen (14) hours (sufficient to evaporate the sweat absorbed during the previous day's wear), the individual items of clothing were weighed in the hot room, within 5 grams, immediately before and after walking. Table 13 indicates that the flameproofed garments absorbed less than half as much sweat (water) as the herringbone twill garments. Furthermore, this difference in water uptake was the same in both the saturated and the more dry environments (Table 13). Since the total sweat output of the men was the same when wearing both types of clothing, equal opportunities for the absorption of water were presented to both garments. It also appeared that most of the water taken up by the flameproofed garments was absorbed early for the increase in weight of the clothing of men dropping out in one or two hours almost equalled that of the clothing of the men

Incl. #1

who completed four (4) hours of work.

The water repellancy of the flameproofed clothing decreased with wear (Table 14). However, this clothing never absorbed more than one-half as much water as the herringbone twill. The increase in water absorbing capacity was not due to the leaching out of the flameproofing compound since the weight of the flameproofed garments did not decrease with wear (Table 12).

Determinations of the absorption of water by the flameproofed long cotton underwear were few, but indicated that (1) when relatively small amounts of sweat are present, the flameproofed underwear takes up as much sweat as the cotton underwear and (2) when larger amounts of sweat are present the uptake falls progressively below that for the untreated cotton (Table 15).

(2) Uptake of Water on Immersion

The absolute differences in the total water absorbing capacities of herringbone twill and flameproofed twill were determined by weighing the two types of clothing before and after immersion in water. The individual items of clothing were dried, weighed, and then immersed in water at 72°F (22°C) for both four and forty-five hours, removed and hung individually. The clothing was reweighed when the drippage rate was 4 drops per minute. It was again hung and then reweighed at intervals to determine the drying rate. This was determined in two environments: (1) D.B. 72°F, W.B. 65°F and (2) D.B. 120°F, W.B. 68°F.

Table 16 indicates that herringbone twill jackets and trousers absorbed water in amounts equal to their initial dry weights; whereas similar flameproofed garments absorbed only about one-half of their dry weight. However, in terms of water absorbed, the actual uptake by the flameproofed garments was approximately two-thirds of the uptake by the herringbone twill garments. Similarly, flameproofed long cotton underwear absorbed but 75% to 85% as much water as regular cotton long underwear. A comparison of Table 16 with Tables 13 and 14 indicates that during wear, herringbone twill garments absorbed sweat in amounts approximating 95% of the total water absorptive power of the cloth. On the other hand, during wear, flameproofed garments absorbed 50% to 60% of the water they were capable of absorbing. Determinations of the amount evaporated per unit time from the two types of clothing indicated that they were approximately the same. However, since the flameproofed clothing had absorbed less water (Chart 12), it became dry more rapidly than the herringbone twill.

c. Effect of Clothing on the Evaporation Gradient Between Skin and Air

It appeared that the flameproofed clothing imposed a greater barrier to the evaporation of sweat than did the herringbone twill. A series of experiments were designed to test this hypothesis and quantitate the effect of clothing on the evaporative gradient between skin and air.

These tests were made in an environment of D.B. 120°F, W.B. 92°F on two men of similar physical characteristics and with essentially identical physiologic responses to work in the heat. The two men were studied nude, in herringbone twill, in flameproofed twill and in prewetted flameproofed twill. The standard conditions consisted of having the men stand for one-half hour in a wide pan containing mineral oil under which unevaporated sweat collected. The subject's dry clothing, a thermocouple harness, a "test" towel and the pan were weighed while the man dried himself

Incl. #1

thoroughly with a "discard" towel. The pan was placed on the weighing platform, the subject quickly donned the harness and test clothing, then stepped into the pan. The weight of clothed man plus pan was obtained at the beginning and end of 30 minutes. The change in weight indicated evaporated sweat. During the stand, the skin temperature (by thermocouple from 4 areas) and the surface temperature (by radiometer from 5 areas) were determined five times. When the man was nude, skin temperature readings were made by radiometer. Dry and wet bulb temperatures of the air at the subject's chest level were determined 3 times during the stand and the heart rate and rectal temperature were taken at the beginning and end. At the end of 30 minutes, the final weight and temperature data were taken, the subject undressed, dried in the "test" towel following which the removed clothing and harness, towel and pan were weighed.

From this data were calculated the total sweat loss, the evaporated sweat and its heat equivalent, the mean (average) skin temperature, the vapor pressure of the air, the vapor pressure of water at the temperature of the skin, and the change in body heat content (heat storage). Coefficients used in the storage calculations were 0.33 for skin temperature and 0.67 for rectal temperature and 0.83 for the specific heat of the body.

Table 17 presents the derived data of these experiments. It indicates the extent to which clothing imposed a barrier to evaporative cooling for the standing subject. Flameproof twill imposed a greater barrier than herringbone twill as shown by the smaller volume of sweat evaporated and the decreased heat lost by its evaporation. Herringbone twill cloth decreases the total evaporative heat loss observed in the nude subject by 17% and flameproofed twill cloth by 27%. The evaporative gradient (Calories of heat lost per square meter of body surface per mm Hg difference in vapor pressure of the water at the temperature of the skin and air) follows the same pattern being lowered 13% by herringbone twill and 28% by flameproofed twill (nude, 9.9; herringbone twill, 8.6; flameproofed twill, 7.1).

The physiologic implications of these clothing barriers to evaporative cooling are the progressively higher skin and rectal temperatures and the gain in body heat content as the men went from the nude state to herringbone twill to flameproofed clothing. For example, when nude, the men were in thermal equilibrium and stored no heat; when wearing herringbone twill, they stored heat at the rate of 8.2 Calories/M^2/Hour; and when in flameproofed twill, their heat storage was about twice as great, being 14.4 Calories/M^2/Hour.

Wearing flameproofed garments which had been previously wetted by immersion yielded total evaporative heat losses and evaporative gradients which closely approximated those for the nude state (Table 17). However, it is likely that they do not represent the actual heat loss from the body for a considerable amount of the evaporation probably took place at the surface of the clothing and not at the skin surface. Evaporation at the clothing surface may not be as beneficial in cooling the body. That this may indeed have been the case is indicated by a definite heat storage of 6.2 Calories/M^2/Hour during wearing of the prewetted garments; whereas no heat storage occurred in the nude state where similar evaporative heat losses and evaporative gradients were obtained.

An evaluation of the real meaning of the evaporative gradients here determined is complicated by the progressive wetting of the clothing during the test period. Hence the gradient is in a sense a mixed one, pertaining neither to dry clothing nor

Incl. #1

to wet clothing, but to an indefinite state of the clothing which is progressively changing from dry to wet.

5. Toxic Effects

No toxic effects attributable to the impregnation were encountered during this study in which some men wore the flameproofed garments as many as 18 times for a total of 46 hours of wear. The garments were not worn continuously throughout the day, but rather intermittently during test periods varying from 1 to 4 hours in length. Neither generalized systemic effects nor cutaneous toxic reactions resulting from direct contact were seen.

However, an erythematous and maculo-papular dermatitis was noted in some subjects when wearing either herringbone twill or flameproofed garments. These resulted from the mechanical irritation of the cloth, being localized to areas where rubbing occurred, such as the groins, anterior surface of the thighs, the upper thorax, the belt line and lower legs.

The intermittent and relatively short duration of wear of these garments did not constitute an entirely satisfactory test of the toxic potentialities of the impregnite. Nevertheless, acute toxicity can be excluded by these experiments.

6. Flame Resistance of the Clothing

This has been reported separately.*

*N.R.C. Project Q.M.C. No. 27, Preliminary Report, Sub-Project 27-A5-X-2, dated 30 April 1945.

Incl. #1

TABLE 3

The Physiologic Responses of Working Men Wearing
Increasing Amounts of Flameproofed Twill

D.B. 100°F. - W.B. 80°F.

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F Hours 0	1	2	3	4	PULSE RATE/MIN. Hours 0	1	2	3	4	SKIN TEMP. (Avg.Wtg.) °F Init.	Final	WEIGHT LOSS (Sweat) Gr/Hr.
NUDE	B	Kac	98.4	99.1	99.1	99.1	99.0	99	99	105	102	102	94.8	92.3	448
		Sco	99.2	100.3	100.1	100.0	99.7	102	105	108	105	102	95.7	92.4	639
		Mic	98.6	99.3	99.1	98.9	99.0	93	90	93	90	87	95.5	94.3	451
		Low	98.6	99.6	99.3	99.1	99.0	105	108	102	99	99	96.4	93.5	520
		AVG.	98.7	99.5	99.4	99.3	99.2	100	100	102	99	98	95.6	93.1	514
F.P.(D) SINGLE LAYER	B	Kac	98.6	99.0	98.9	98.9	99.0	99	120	108	105	108	93.5	93.6	709
		Sco	98.7	99.7	100.0	99.6	99.5	96	99	102	99	96	95.9	92.8	938
		Mic	98.6	99.1	99.3	99.3	99.4	90	96	99	96	99	97.5	93.5	759
		Low	98.9	99.4	99.6	99.3	99.5	93	93	102	105	93	94.7	94.1	857
		AVG.	98.7	99.3	99.5	99.3	99.4	95	102	103	101	99	95.4	93.5	816
F.P.(D) DOUBLE LAYER	B	Kac	98.7	99.4	99.6	99.2	99.1	96	102	99	102	105	94.0	94.2	759
		Sco	99.2	100.0	100.0	99.8	99.9	114	108	99	105	102	94.9	95.1	1357
		Mic	98.5	99.2	99.2	99.1	99.2	99	96	96	102	96	94.4	94.3	1051
		Low	98.6	99.4	99.9	99.5	99.4	84	102	93	102	93	94.8	94.1	877
		AVG.	98.8	99.5	99.7	99.4	99.4	98	102	97	103	99	94.5	94.4	1011
F.P.(D) COMPLETE ASSEMBLY	B	Kac	98.2	99.1	98.9	99.0	99.1	111	114	102	108	108	94.9	94.8	850
		Sco	99.0	100.5	100.6	99.8	100.1	93	123	114	111	105	95.8	94.2	1237
		Mic	98.9	99.5	99.4	99.1	99.1	111	114	99	90	96	95.3	94.8	1055
		Low	98.8	99.7	99.6	99.3	99.5	105	117	105	108	102	95.8	95.4	831
		AVG.	98.7	99.7	99.6	99.3	99.5	105	117	105	104	103	95.4	94.8	992

Inc. #2

TABLE 4

The Physiologic Responses of Working Men Wearing
Two Layer Flameproofed Twill and Herringbone Twill

D.B. 100°F. - W.B. 80°F.

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F Hours 0	1	2	3	4	PULSE RATE/MIN. Hours 0	1	2	3	4	SKIN TEMP. (Avg.Wtg.) °F Init.	Final	WEIGHT LOSS (Sweat) Gm/Hr.
NUDE	A	Lin	98.7	100.2	100.3	100.2	100.2	102	117	108	102	105	95.2	94.6	502
		Kne	98.9	99.7	99.1	99.0	99.0	96	96	84	87	87	94.4	93.0	560
		Mar	98.6	99.1	99.4	99.3	99.1	102	111	102	96	99	95.4	93.2	549
		Dim	98.7	99.7	99.3	99.4	99.4	96	105	99	99	96	95.6	93.5	433
		AVG.	98.7	99.7	99.5	99.5	99.4	99	107	98	96	97	95.1	93.6	511
NUDE	B	Kac	98.4	99.1	99.1	99.1	99.0	99	99	105	102	102	94.8	92.3	448
		Sco	99.2	100.3	100.1	100.0	99.7	102	105	108	105	102	95.7	92.4	639
		Mic	98.6	99.3	99.1	98.9	99.0	93	90	93	90	87	95.5	94.3	451
		Low	98.6	99.6	99.3	99.1	99.0	105	108	102	99	99	96.4	93.5	520
		AVG.	98.7	99.6	99.4	99.3	99.2	100	101	102	99	98	95.6	93.1	514
H.B.T.	A	Lin	98.9	99.6	99.6	99.5	99.5	78	93	108	96	96	95.0	94.2	1155
		Kne	99.1	99.4	99.2	99.3	99.2	105	108	87	108	84	94.4	94.1	956
		Mar	98.4	99.3	99.8	99.8	99.6	84	96	99	117	105	94.3	95.7	859
		Dim	98.8	99.5	99.8	99.9	99.8	87	93	87	108	96	94.8	93.8	823
		AVG.	98.8	99.5	99.6	99.6	99.5	89	98	95	107	95	94.6	94.5	948
F.P.(D)	B	Kac	98.7	99.4	99.6	99.2	99.1	96	102	99	102	105	94.0	94.2	759
		Sco	99.2	100.0	100.0	99.8	99.9	114	108	99	105	102	94.9	95.1	1357
		Mic	98.5	99.2	99.2	99.1	99.2	99	96	96	102	96	94.4	94.3	1051
		Low	98.6	99.4	99.9	99.5	99.4	84	102	93	102	93	94.8	94.1	877
		AVG.	98.6	99.5	99.7	99.4	99.4	98	102	97	103	99	94.5	94.4	1011

Incl. #2

TABLE 5

The Physiologic Responses of Working Men Wearing Two Layer Flameproofed Twill and Herringbone Twill

D.B. 100°F. - W.B. 86°F.

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F					PULSE RATE/MIN.					SKIN TEMP. (Avg. Wtg.) °F		WEIGHT LOSS (Sweat)
			Hours					Hours							Gm/Hr.
			0	1	2	3	4	0	1	2	3	4	Init.	Final	
H.B.T.	A	Lin	99.1	100.2	100.6	100.3	100.0	93	126	105	126	117	96.2	94.8	2110
		Kne	98.5	100.0	100.0	99.4	99.3	102	129	99	120	111	95.8	94.3	1457
		Mar	98.2	100.0	100.2	100.1	100.2	105	144	138	135	126	96.1	95.7	1362
		Dim	98.5	99.9	100.5	100.2	100.2	90	132	129	120	120	95.4	94.6	1281
		AVG.	98.6	100.0	100.3	100.0	99.9	98	133	118	125	119	95.9	95.0	1552
F.P.(D)	B	Kac	98.4	99.7	99.9	99.8	99.8	96	144	132	129	120	94.9	94.9	1213
		Sco	98.8	100.3	101.0	100.3	100.4	120	147	156	141	129	95.6	95.2	2005
		Mic	98.4	100.0	101.0*	-	-	117	153	171*	-	-	-	-	2198
		Low	98.6	100.1	100.4	100.4	100.3	105	129	132	120	129	96.0	95.8	1321
		AVG.	98.6	100.0	100.6	100.2	100.2	110	143	148	130	126	95.5	95.3	1684

*Unable to continue after two (2) hours of walking.

Incl. #2

TABLE 6

The Physiologic Responses of Working Men Wearing
Two Layer Flameproofed Twill and Herringbone Twill

D.B. 90°F. - W.B. 88°

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F					PULSE RATE/MIN.					SKIN TEMP. (Avg.Wtg.) °F		WEIGHT LOSS (Sweat)
			Hours 0	1	2	3	4	Hours 0	1	2	3	4	Init.	Final	Gm/Hr.
H.B.T.	A	Lin	99.0	100.2	100.2	100.0	100.1	99	102	102	117	117	96.2	95.2	2026
		Kne	98.9	100.0	99.8	99.4	99.6	102	104	93	108	117	95.7	95.4	1230
		Mar	99.0	100.3	100.4	100.0	100.3	129	117	117	120	123	96.4	95.6	1150
		Dim	98.2	100.0	100.7	100.5	100.9	69	102	120	120	132	94.6	95.5	1117
		AVG.	98.8	100.1	100.3	100.0	100.2	100	106	108	116	122	95.7	95.4	1381
F.P.(D)	B	Kac	98.8	99.6	99.8	99.9	100.0	114	117	126	132	141	95.1	96.2	1113
		Hil	99.1	99.8	100.1	99.7	100.1	99	102	114	123	120	95.9	96.3	1218
		Mic	99.0	99.9	100.0	100.2	100.3	111	102	126	138	144	95.2	96.8	1653
		Low	98.5	99.7	100.0	100.2	100.4	111	114	120	135	141	94.5	96.3	1201
		AVG.	98.8	99.8	100.0	100.0	100.2	109	109	122	132	137	95.2	96.4	1296

Incl. #2

TABLE 7

The Physiologic Responses of Working Men Wearing
Flameproofed Twill and Herringbone Twill

D.B. 120°F. - W.B. 88°F.

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F Hours 0	1	2	3	4	PULSE RATE/MIN. Hours 0	1	2	3	4	SKIN TEMP. (Avg. Wtg.) °F Init.	Final	WEIGHT LOSS (Sweat) Gm/Hr.
NUDE	A	Dim	99.1	100.1	100.0	100.2	100.0	99	114	120	108	99	97.6	96.9	1024
		Szu	98.7	99.2	99.3	99.2	99.3	108	111	105	99	114	97.2	97.0	909
		Mar	98.5	99.5	99.7	99.6	99.6	96	102	111	105	120	97.8	97.7	1054
		Lin	98.4	99.7	99.6	99.6	99.8	84	96	105	102	105	97.1	96.0	1444
		Kne	98.5	99.1	99.3	99.0	99.0	93	111	120	84	87	97.4	97.2	1005
		AVG.	98.6	99.5	99.6	99.5	99.5	96	107	112	100	105	97.4	97.0	1087
NUDE	B	Low	98.5	99.9	100.0	100.0	100.1	96	108	105	108	120	97.7	98.2	1148
		Mic	98.8	99.6	99.6	99.6	100.0	126	129	126	123	135	96.3	96.2	1062
		Hil	98.3	99.5	99.4	99.6	99.8	102	120	111	108	126	96.5	96.9	1022
		Kac	98.6	99.6	99.5	99.6	99.7	99	108	117	120	126	97.0	97.7	982
		Sco	98.8	99.9	100.1	100.2	100.0	114	117	117	99	105	99.1	96.7	1388
		AVG.	98.6	99.7	99.7	99.8	99.9	107	116	115	112	122	97.3	97.1	1120
H.B.T.	B	Low	98.7	100.3	100.6	101.0	100.5	120	135	138	129	126	98.6	98.0	1812
		Mic	99.0	99.8	99.9	99.7	99.7	99	123	132	123	123	98.7	97.1	1756
		Hil	98.6	100.2	100.4	100.5	100.5	105	141	135	135	126	96.6	97.1	1544
		Kac	98.6	100.2	100.2	100.3	100.2	123	135	132	132	126	96.6	97.2	1499
		Sco	98.6	100.6	100.4	100.2	100.0	117	138	117	111	129	98.4	96.7	2039
		AVG.	98.7	100.2	100.3	100.3	100.2	113	134	131	126	126	97.8	97.2	1730
F.P.(D)	A	Dim	98.4	101.3	101.6	101.3	101.0	81	135	132	129	132	97.2	97.8	1701
		Szu	98.4	100.6	101.4	101.4	101.4	99	129	135	138	129	97.7	98.7	1482
		Mar	98.6	101.2	101.5	101.3	101.0	111	153	153	153	144	97.8	98.0	1752
		Lin	98.8	101.7	102.3	102.4	102.5	96	120	117	126	123	97.7	99.7	2040
		Kne	98.8	100.8	101.5	101.6	101.5	102	123	117	108	117	97.2	99.1	1755
		AVG.	98.6	101.1	101.7	101.6	101.5	98	132	131	131	129	97.5	98.7	1746

Incl. #1

TABLE 8

The Physiologic Responses of Working Men
Wearing Flameproofed Twill and Herringbone Twill

D.B. 120°F. - W.B. 90°F.

CLOTHING	GROUP	NAME	HRS.WALKED	RECTAL TEMPERATURE °F Hours 0	1	2	3	4	PULSE RATE/MIN. Hours 0	1	2	3	4	SKIN TEMP. (Avg.Wtg.) °F Init.	Final	WEIGHT LOSS (Sweat) Gm/Hr.
NUDE	A	Dim	4.0	99.0	100.2	100.4	100.4	100.4	90	117	120	117	117	96.9	96.8	1477
		Szu	4.0	99.1	99.8	99.7	99.6	99.8	111	111	114	117	114	97.9	96.7	1614
		Mar	4.0	98.0	100.1	100.9	100.2	100.4	105	141	123	129	123	97.0	96.8	1725
		Lin	4.0	99.0	100.5	100.7	100.5	100.4	96	111	123	117	117	97.7	96.9	2245
		Kne	4.0	98.3	99.9	100.1	99.9	99.9	99	126	117	117	123	97.0	97.5	1642
		AVG.		98.7	100.1	100.4	100.1	100.2	100	121	119	119	119	97.3	96.9	1741
NUDE	B	Low	4.0	98.4	99.6	100.2	99.9	100.2	96	114	120	120	117	96.5	97.8	1645
		Mic	4.0	98.5	100.0	100.5	100.4	100.3	117	126	129	123	123	97.6	96.8	1901
		Hil	4.0	96.7	99.7	100.0	99.9	99.9	108	123	111	111	117	96.5	96.4	1477
		Kac	4.0	98.6	99.7	99.8	99.7	99.8	102	123	123	120	114	96.3	97.2	1421
		Sco	4.0	99.0	100.4	100.3	99.9	100.1	111	129	126	123	123	97.7	96.9	2239
		AVG.		98.6	99.9	100.2	100.0	100.1	107	123	122	119	119	96.9	97.0	1737
H.B.T.	B	Low	4.0	98.4	100.7	101.2	100.9	100.8	96	120	129	132	135	97.3	97.9	1543
		Mic	4.0	98.3	100.7	101.2	101.0	101.0	102	120	153	138	138	97.3	97.3	2123
		Hil	4.0	99.3	100.6	101.0	100.1	100.0	102	117	126	123	117	97.1	97.3	1859
		Kac	4.0	98.4	100.4	100.7	100.3	100.0	111	135	129	123	132	97.3	97.2	1711
		Sco	4.0	98.7	100.8	100.6	100.3	100.2	105	123	135	126	120	98.2	97.1	2693
		AVG.		98.6	100.6	100.9	100.5	100.4	103	123	134	128	128	97.4	97.4	1986
F.P.(D)	A	Dim	2.0	98.5	100.9	101.8*	-	-	96	126	141*	-	-	98.1	97.6*	1843
		Szu	4.0	98.4	100.4	100.6	101.0	100.6	108	126	144	144	126	96.9	98.2	1988
		Mar	2.4	98.6	101.5	102.9	102.8*	-	117	138	156	156*	-	97.8	97.1*	2376
		Lin	4.0	98.8	101.4	102.0	101.9	101.8	102	147	150	138	153	97.7	98.1	3121
		Kne	2.7	98.8	101.1	101.8	102.0*	-	114	123	145	147*	-	97.0	98.7*	2231
		AVG.		98.6	101.1	101.8	101.4	101.2	107	132	147	141	140	97.5	98.2	2312

*Data taken at time of cessation of walking - not used in averages for that hour.

Incl. #2

CONFIDENTIAL

TABLE 9

The Physiologic Responses of Working Men
Wearing Flameproofed Twill and Herringbone Twill

D.B. 120°F. - W.B. 92°F.

CLOTHING	GROUP	NAME	HRS. WALKED	RECTAL TEMPERATURE °F Hours 0	1	2	3	4	PULSE RATE/MIN. Hours 0	1	2	3	4	SKIN TEMP. (Avg.Wtg.) °F Init.	Final	WEIGHT LOSS (Sweat) Gm/Hr.
NUDE	A	Dim	4.0	98.8	100.9	101.0	100.9	101.1	93	135	132	120	120	97.5	97.6	1790
		Szu	4.0	98.9	100.2	100.1	100.8	100.9	105	129	123	129	126	97.6	98.6	1747
		Mar	4.0	97.8	100.4	100.5	100.7	100.6	99	141	123	126	120	97.4	97.8	2325
		Lin	4.0	99.2	101.2	101.2	101.0	101.1	96	126	126	117	123	97.6	98.6	2294
		Kne	4.0	98.4	100.2	100.3	100.2	100.9	87	123	99	123	120	96.8	99.1	1949
		AVG.		98.6	100.6	100.6	100.7	100.9	96	131	121	123	122	97.4	98.3	2021
NUDE	B	Low	4.0	98.6	100.1	101.4	101.7	102.1	102	144	129	120	132	98.1	99.4	1396
		Mic	4.0	98.8	100.3	100.4	100.5	101.0	105	126	150	123	126	97.8	98.7	2071
		Hil	4.0	98.4	100.4	100.4	100.4	100.6	87	111	102	117	111	97.2	98.7	1562
		Kac	4.0	98.6	100.0	100.0	100.2	100.7	96	120	120	132	123	97.1	98.5	1684
		Sco	4.0	99.3	101.4	101.2	101.2	101.5	111	156	123	120	126	97.8	98.2	2543
		AVG.		98.7	100.4	100.7	100.8	101.2	100	131	125	122	124	97.6	98.7	1851
H.B.T.	B	Low	2.4	98.9	102.0	103.1	103.2*	-	105	144	144	150*	-	98.0	100.4*	1589
		Mic	2.7	98.8	101.3	101.8	102.4*	-	129	147	141	156*	-	98.3	99.6*	2063
		Hil	4.0	98.2	100.8	101.7	101.7	102.0	102	129	111	147	123	97.9	99.4	1688
		Kac	4.0	98.7	101.2	102.0	102.0	101.8	105	150	147	141	150	97.2	99.3	1774
		Sco	4.0	99.0	102.0	102.3	102.4	102.5	114	147	132	132	126	98.1	99.2	2477
		AVG.		98.7	101.5	102.2	102.0	102.1	111	143	135	140	133	97.9	99.3	1718
F.P.(D)	A	Dim	1.6	98.6	102.2	103.4*	-	-	105	141	132*	-	-	97.4	99.8*	1957
		Szu	2.0	98.8	101.6	102.9*	-	-	117	138	135*	-	-	98.7	100.5*	1955
		Mar	1.2	97.8	102.1	102.8*	-	-	99	180	168*	-	-	97.5	100.3*	2397
		Lin	1.6	99.1	102.8	103.6*	-	-	108	141	129*	-	-	98.2	100.4*	2569
		Kne	4.0	98.6	102.0	103.5	103.7	103.4	102	141	141	138	141	97.9	100.8	1824
		AVG.		98.6	102.1	103.2	103.7	103.4	106	148	138	138	141	97.9	100.8	2140

*Data taken at time of cessation of walking - not used in averages for that hour.

CONFIDENTIAL

Incl. #2

TABLE 10

The Physiologic Responses of Working Men Wearing
Flameproofed Twill and Herringbone Twill

D.B. 93°F. - W.B. 92°F.

CLOTHING	GROUP	NAME	RECTAL TEMPERATURE °F					PULSE RATE/MIN.					SKIN TEMP. (Avg.Wtg.) °F		WEIGHT LOSS (Sweat)
			Hours 0	1	2	3	4	Hours 0	1	2	3	4	Init.	Final	Gm/Hr.
NUDE	A	Dim	98.8	100.0	100.4	100.6	100.6	93	129	114	123	117	95.3	96.4	1706
		Szu	98.0	99.4	99.5	99.8	99.8	87	108	120	123	123	95.2	96.8	1705
		Mar	98.4	100.3	100.7	100.8	100.6	120	150	153	141	138	95.3	96.7	1791
		Lin	99.7	100.7	100.6	100.7	100.6	93	117	108	117	126	96.4	96.5	1908
		Kne	98.4	99.8	100.1	100.4	100.3	90	114	117	117	120	94.8	97.0	1848
		AVG.	98.7	100.0	100.3	100.5	100.4	97	124	122	124	125	95.4	96.7	1792
NUDE	B	Low	98.6	100.4	100.7	101.0	101.2	90	150	129	120	126	93.0	97.3	1466
		Mic	98.6	99.9	100.6	100.5	100.6	114	132	153	129	126	95.1	96.8	1836
		Hil	98.6	99.6	99.9	100.0	99.9	93	99	114	126	105	95.0	96.8	1483
		Kac	99.3	100.2	100.3	100.7	101.4	102	126	126	138	129	94.6	97.1	1148
		Sco	98.8	100.5	100.8	100.8	101.1	105	141	123	126	129	95.8	96.6	2458
		AVG.	98.8	100.1	100.5	100.6	100.8	101	130	129	128	123	94.7	96.9	1678
H.B.T.	A	Dim	98.5	101.0	101.1	101.3	101.4	93	135	135	123	132	95.6	97.8	1760
		Szu	98.7	100.6	101.5	101.0	100.7	105	129	141	132	123	95.9	97.9	1760
		Mar	98.1	100.9	101.6	101.3	101.6	102	141	144	150	156	95.9	97.6	2244
		Lin	99.4	101.7	102.3	102.0	102.1	105	135	126	144	144	96.6	98.1	2353
		Kne	98.5	100.9	101.2	101.0	101.0	108	120	129	129	123	95.8	98.2	1824
		AVG.	98.6	101.0	101.5	101.3	101.4	103	132	135	136	136	96.0	97.9	1988
F.P.(D)	B	Low	98.6	101.3	101.7	102.0	102.1	93	129	147	135	138	96.2	98.7	1476
		Mic	98.6	100.8	101.4	101.3	102.0	108	138	135	144	153	96.2	98.1	1961
		Hil	98.5	100.8	101.5	101.3	101.4	99	132	129	123	126	95.1	98.1	1650
		Kac	99.3	101.0	101.8	102.2	102.4	105	129	150	153	150	95.7	98.8	1486
		Sco	98.6	101.0	101.7	101.7	101.7	102	147	159	135	147	96.4	98.5	2914
		AVG.	98.7	101.0	101.6	101.7	101.9	101	135	144	138	143	95.9	98.4	1897

Incl. #2

TABLE 11

The Physiologic Responses of Working Men
Wearing Flameproofed Twill and Herringbone Twill

D.B. 95°F. - W.B. 94°F.

CLOTHING	GROUP	NAME	HRS. WALKED	RECTAL TEMPERATURE °F					PULSE RATE/MIN.					SKIN TEMP. (Avg. Wtg.) °F		WEIGHT LOSS (Sweat)
				Hours					Hours							Gm/Hr.
				0	1	2	3	4	0	1	2	3	4	Init.	Final	
NUDE	A	Dim	4.0	98.6	100.6	101.4	101.1	101.0	96	132	129	120	120	94.9	96.8	1833
		Szu	4.0	98.0	99.8	100.6	100.9	101.0	105	123	138	123	123	95.3	97.1	2256
		Mar	4.0	98.5	100.3	101.5	101.6	101.5	114	162	159	150	159	95.1	96.9	2265
		Lin	4.0	98.6	100.8	102.0	101.7	102.1	90	126	135	132	144	95.0	97.1	2626
		Kne	4.0	98.9	100.0	100.7	100.8	101.2	105	129	135	138	129	96.0	97.3	1818
		AVG.		98.5	100.3	101.2	101.2	101.4	102	134	139	133	135	95.3	97.0	2160
NUDE	B	Low	4.0	99.1	100.8	101.6	102.2	102.6	108	132	135	138	141	96.4	98.1	1771
		Mic	4.0	100.0	100.1	101.0	101.0	101.4	102	129	132	138	144	95.5	97.4	2500
		Hil	4.0	98.7	100.4	101.3	101.1	101.1	96	114	132	132	123	95.4	96.8	1806
		Kac	4.0	98.4	100.0	100.8	100.7	101.0	114	141	147	135	156	95.6	97.2	1600
		Sco	4.0	99.1	100.4	101.1	101.7	101.5	105	138	144	138	132	94.7	97.2	3087
		AVG.		99.1	100.3	101.2	101.3	101.5	105	131	138	136	139	95.5	97.3	2153
H.B.T.	B	Low	2.8	99.1	102.2	103.5	103.4*	-	114	156	156	150*	-	96.7	99.1*	1626
		Mic	1.8	98.6	101.6	102.9*	-	-	120	162	144*	-	-	96.4	98.3*	2356
		Hil	2.2	99.0	101.7	102.8	102.7*	-	114	144	135	150*	-	96.6	98.4*	1804
		Kac	2.0	98.6	101.3	102.7*	-	-	114	159	171*	-	-	96.1	98.3*	2243
		Sco	4.0	98.8	101.7	102.6	103.0	102.9	108	150	153	150	156	95.9	99.2	2586
		AVG.		98.8	101.7	102.9	103.0	102.9	114	154	154	150	156	96.3	99.2	2123
F.P.(D)	A	Dim	1.8	99.0	102.1	103.9*	-	-	92	159	156*	-	-	-	-	1770
		Szu	1.7	98.1	101.1	101.8*	-	-	111	144	144*	-	-	96.3	98.5*	2073
		Mar	1.5	98.6	102.3	103.4*	-	-	114	165	180*	-	-	96.6	99.0*	2113
		Lin	2.0	98.6	102.2	103.9*	-	-	105	150	147*	-	-	96.4	98.5*	2980
		Kne	1.6	98.9	102.0	102.8*	-	-	111	159	144*	-	-	96.0	99.3*	2005
		AVG.		98.6	101.9	103.9	-	-	107	155	147	-	-	96.3	-	2188

*Data taken at time of cessation of walking - not used in averages for that hour.

Incl. #2

TABLE 12

Weight of Test Clothing Before the First
and After the Last Wear

(Data are the Average of Ten Uniforms)

	JACKET	TROUSERS
Herringbone Twill		
Initial Weight (GM)	740	656
Final Weight (GM)	773	684
Flameproof Twill		
Initial Weight (GM)	1098	960
Final Weight (GM)	1106	980

Inc. #2

TABLE 13

The Sweat Absorbed by Flameproofed and Herringbone Twill Two-Piece Fatigue Uniforms During Work in Hot Environments

(Data are the Average for the Clothing of Five Men)

	ENVIRONMENT AND TYPE OF GARMENT			
	D.B. 120°F., W.B. 90°F.		D.B. 93°F., W.B. 92°F.	
	Flameproofed Twill	Herringbone Twill	Flameproofed Twill	Herringbone Twill
Hours of Wear	3.5	4.3	4.2	3.9
Water Absorbed (Grams)				
Jacket	306	697	370	719
Trousers	305	697	381	721
Assembly	611*	1394	751	1440
Total Sweat of Subjects (Grams)	8182	8486	8040	6640

* The clothing assembly of the two men who walked for the entire period had an average water uptake of 663 grams, while the clothing of the remaining three men, walking an average of 2.4 hours, had an uptake of 577 grams.

Inc. #2

TABLE 14

The Increased Uptake of Sweat by Flameproofed Garments During Repeated Wear in Hot Environments

(Data are the Average for the Clothing of 5 Men)

	ENVIRONMENT AND TYPE OF GARMENT		
	D.B.120°F.,W.B.88°F.	D.B.120°F.,W.B.88°F.	D.B.120°F.,W.B.90°F.
	Flameproofed Twill	Flameproofed Twill	Flameproofed Twill
No. of Hours Previous Wear	0	4.6	23.3
Hours of Wear	3.6	4.2	3.5
Water Absorbed (Grams)			
Jacket	130	184	306
Trousers	123	182	305
Assembly	253	366	611*
Total Sweat of Subjects (Grams)	5427	7080	8182

*See Footnote in Table 13.

Incl. #2

TABLE 15

The Sweat Absorbed by the Individual Layers of the Two Layered Flameproofed and Herringbone Twill Fatigue Uniform During Work in Moderately Hot Environments

(Data are the Average for the Clothing of 4 Men)

	ENVIRONMENT AND TYPE OF GARMENT			
	D.B. 100°F., W.B. 80°F.		D.B. 100°F., W.B. 86°F.	
	Flameproofed	Not Flameproofed	Flameproofed	Not Flameproofed
Hours of Wear	4.3	4.3	4.3	4.2
Water Absorbed (Grams)				
Twill Outer Garments	208	609	307*	1175
Cotton Under Garments	550	507	844*	1106
Total Sweat of Subjects (Grams)	4330	4040	6492*	6652

*Data on 3 men only - the data of the one man who failed to finish four hours of walking excluded.

Incl. #2

TABLE 16

The Water Uptake by Individual Items of the Two Layered Flameproofed and Herringbone Twill Uniforms Immersed in Tap Water

(Data is the Average of Two Sets of Clothing)

TYPE OF GARMENT	Weight of Garments in Equilibrium at D.B. 120°F. W.B. 78°F. (Grams)		Water Uptake After Soaking in Water (72°F.) for Four Hours (Grams)		Water Uptake After Soaking in Water (72°F.) for Forty-five Hours (Grams)	
OUTER GARMENTS	Jacket	Trousers	Jacket	Trousers	Jacket	Trousers
Herringbone Twill, Unworn	778	615	749	682	864	700
Flameproof Twill, Unworn	1123	888	506	362	559	384
Herringbone Twill, Worn	778	670	854	777	835	747
Flameproof Twill, Worn	1123	955	562	509	664	513
LONG UNDERGARMENTS	Under-shirt	Drawers	Under-shirt	Drawers	Under-shirt	Drawers
Cotton Regular, Unworn	265	236	543	430	591	514
Cotton Flameproof, Unworn	348	313	441	281	525	323
Cotton Regular, Worn	225	240	607	473	708	595
Cotton Flameproof, Worn	380	339	596	445	504	456

Incl. #2

TABLE 17

Quantitative Determination of the Reduction in Evaporative Heat Loss Due to Flameproofed and Herringbone Twill Uniforms, in a Hot Environment

D.B. 120°F., W.B. 92°F.

(Average of Two Subjects)

	NUDE	HERRINGBONE TWILL	FLAMEPROOFED TWILL	PRE-WETTED FLAMEPROOFED TWILL
Evaporative Heat Loss Cal/M^2/Hr.	160.7	133.2	117.7	163.4
Evaporative Heat Loss Cal/M^2/Hr. per mmHg Vapor Pressure $_{(s-a)}$*	9.9	8.6	7.1	9.7
Change in Heat Content Cal/M^2/Hr.	-2.4	8.2	14.4	6.2
Air Temp. D.B. °F.	121.6	120.0	121.1	120.2
Vapor Pressure of Air, mmHg.	29.2	30.2	30.2	30.5
Final Rectal Temp. °F.	100.9	101.5	101.6	100.8
Average Skin Temp. °F.	97.7	97.7	98.4	98.9
Vapor Pressure at Skin Temp. $_{(s-a)}$ mmHg.	16.5	15.6	16.5	17.0
Sweat, Gm/Hr. Total	1920	1548	1899	1833
Sweat, Gm/Hr. Evaporative	550	458	406	568

*s = skin temperature
a = air temperature

Incl. #2

CHART I

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING INCREASING AMOUNTS OF FLAMEPROOFED TWILL

D.B. 100°F. - W.B. 80°F.

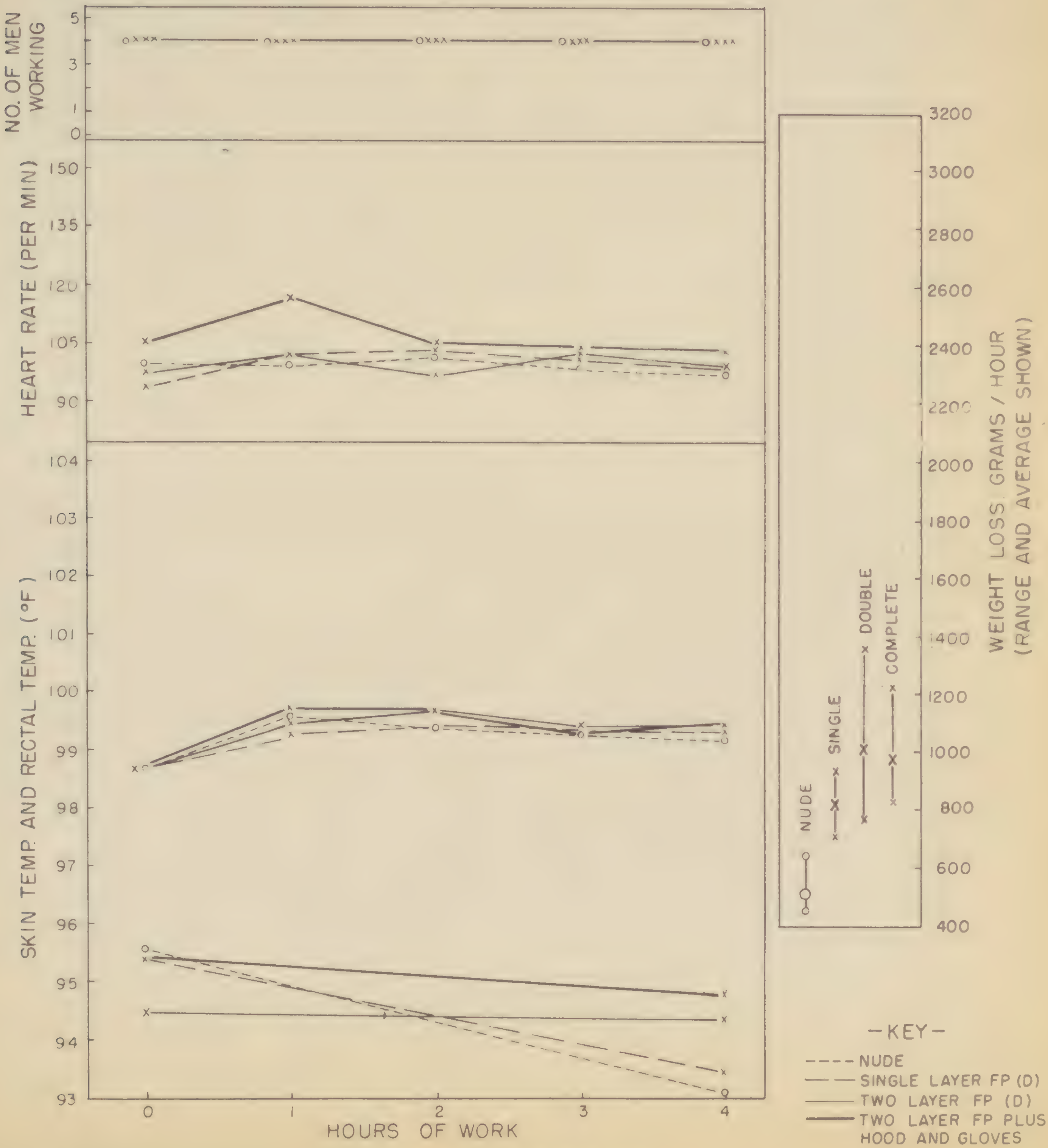


CHART 2

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING TWO LAYER FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D.B. 100° F - W.B. 80° F

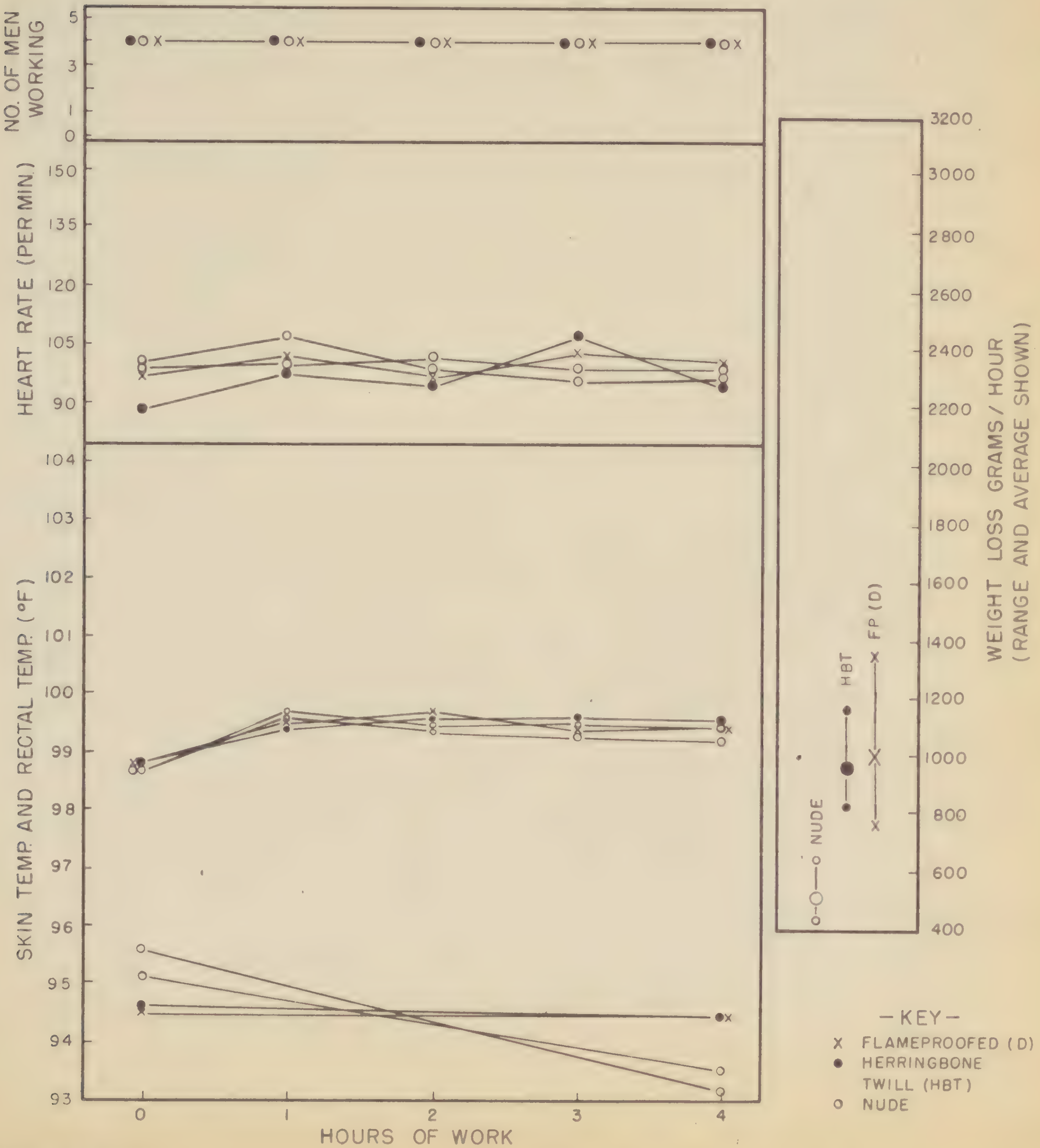
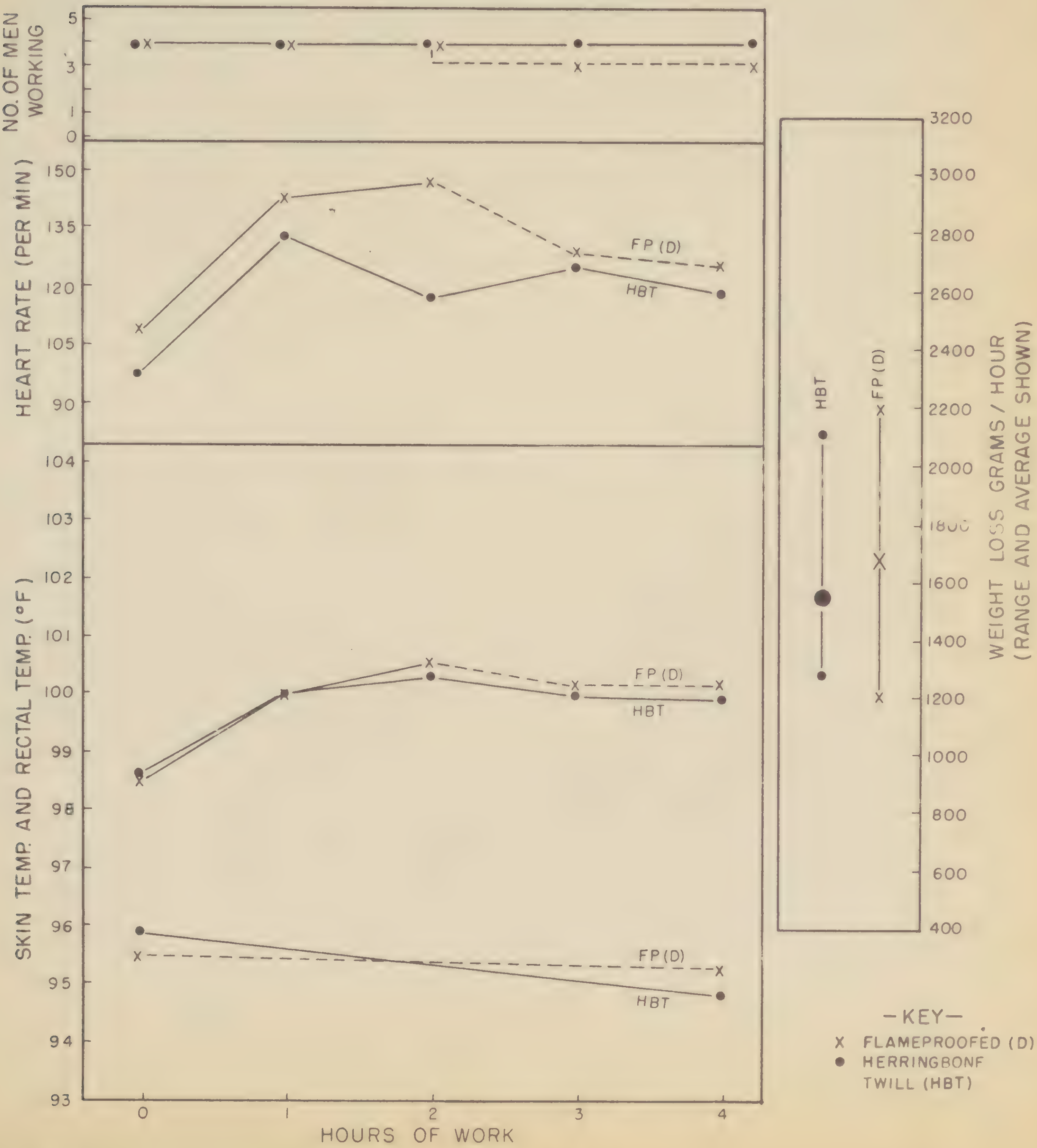


CHART 3

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D. B. 100° F. - W. B. 86° F.



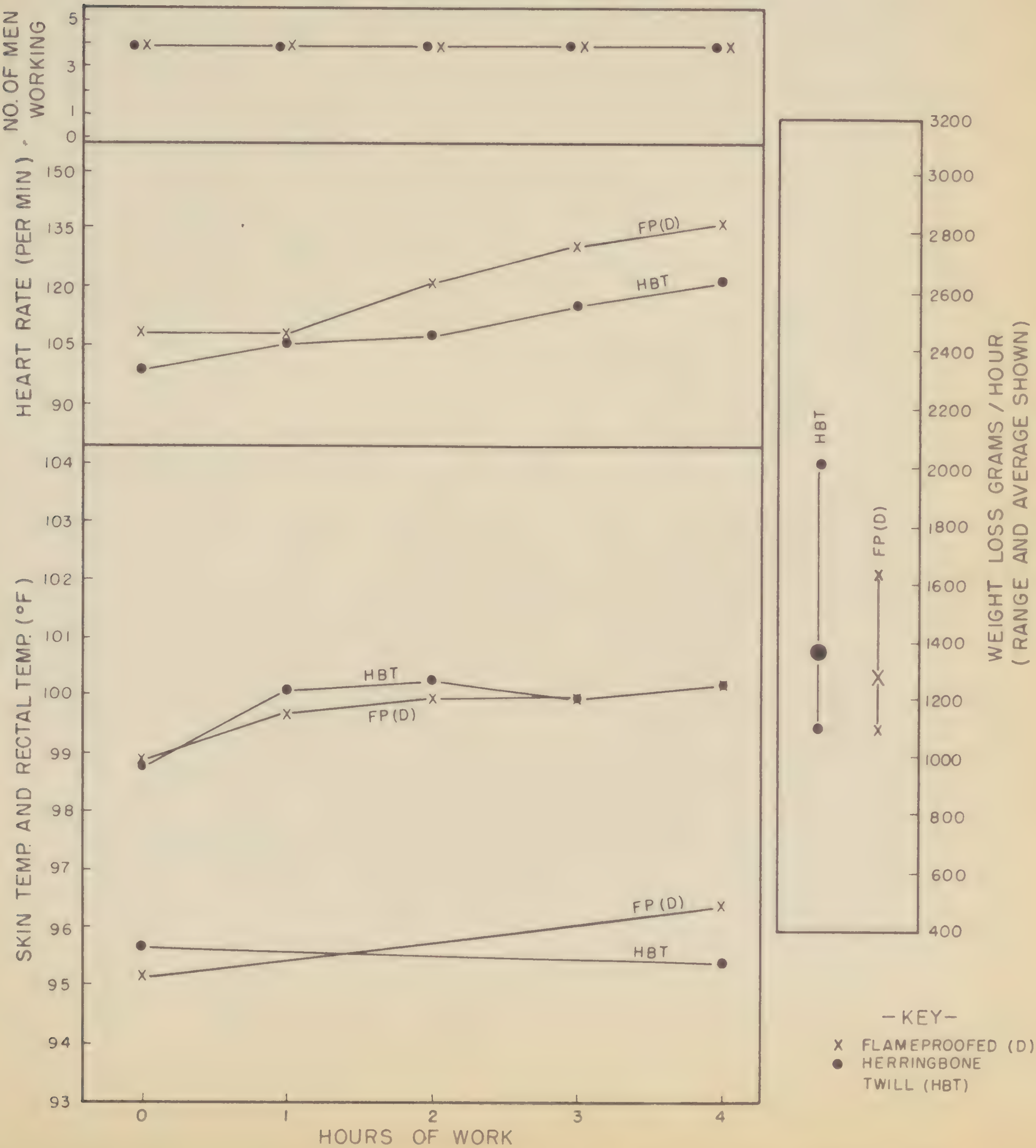
Incl. #3

~~CONFIDENTIAL~~

CHART 4

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING TWO LAYER FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D.B. 90° F.- W.B. 88° F.



Incl. #3

~~CONFIDENTIAL~~

CHART 5

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D.B. 120° F. - W.B. 88° F.

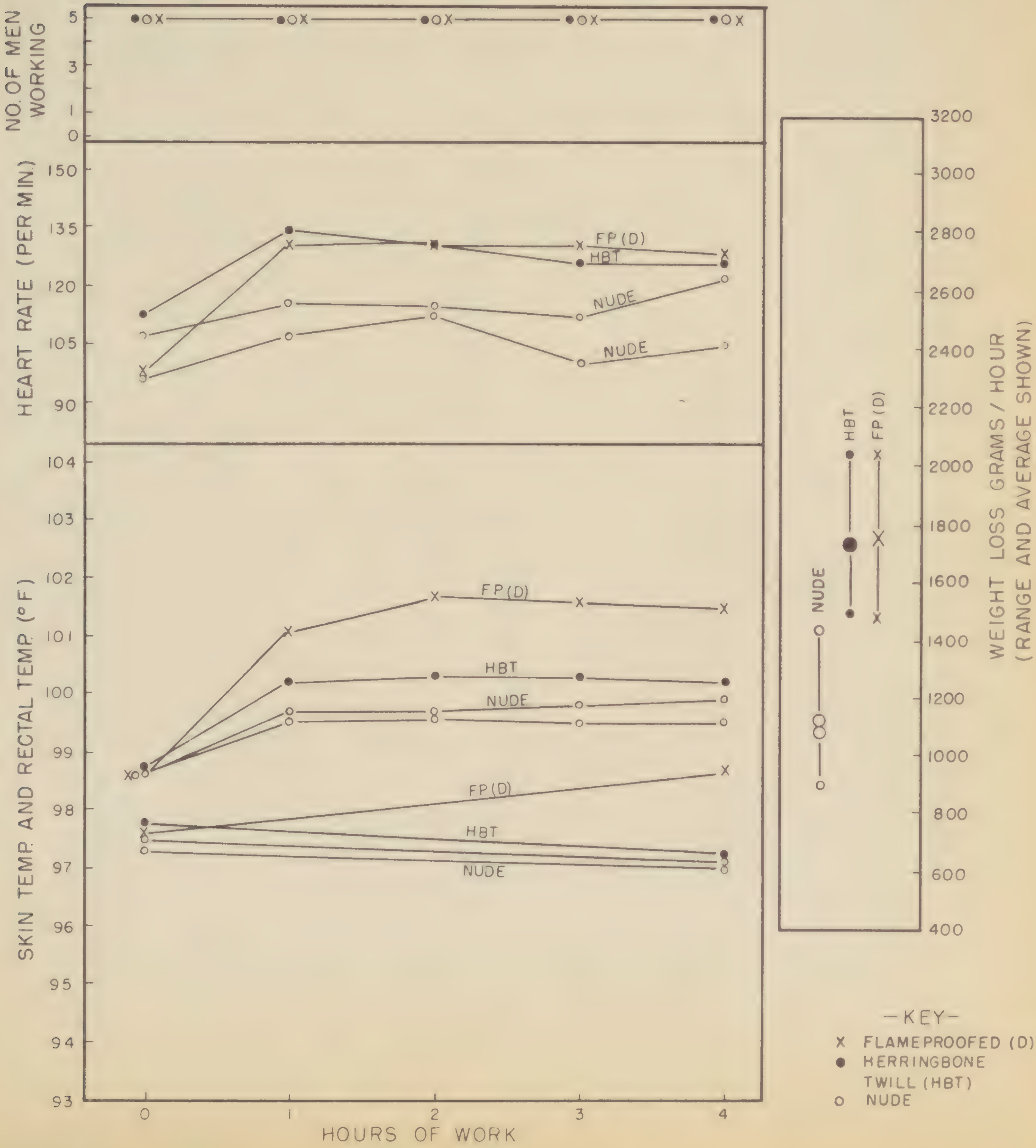
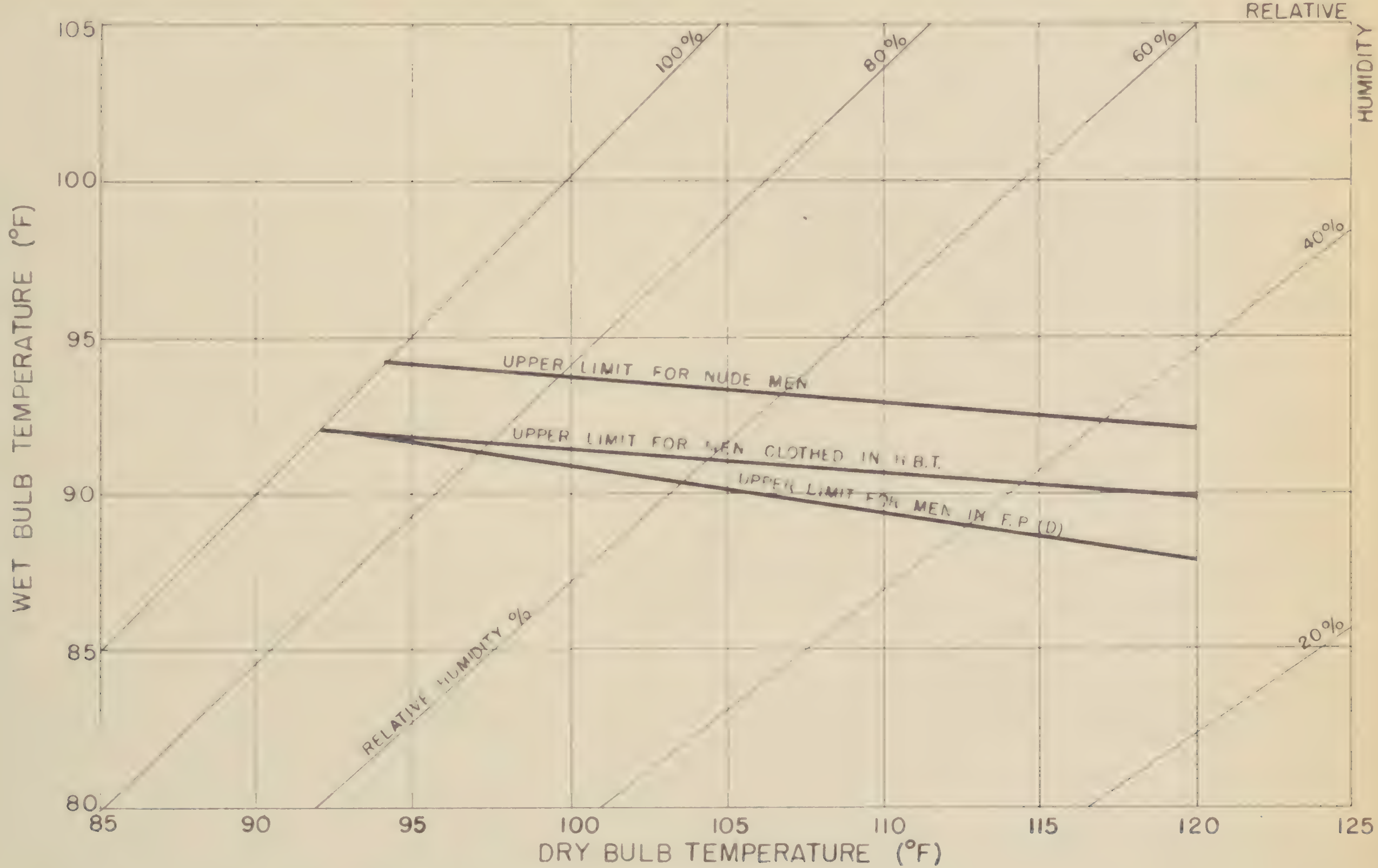


Chart #2

CHART 6

UPPER ENVIRONMENTAL LIMITS AT WHICH MEN CAN COMPLETE FOUR HOURS OF CONTINUOUS WALKING



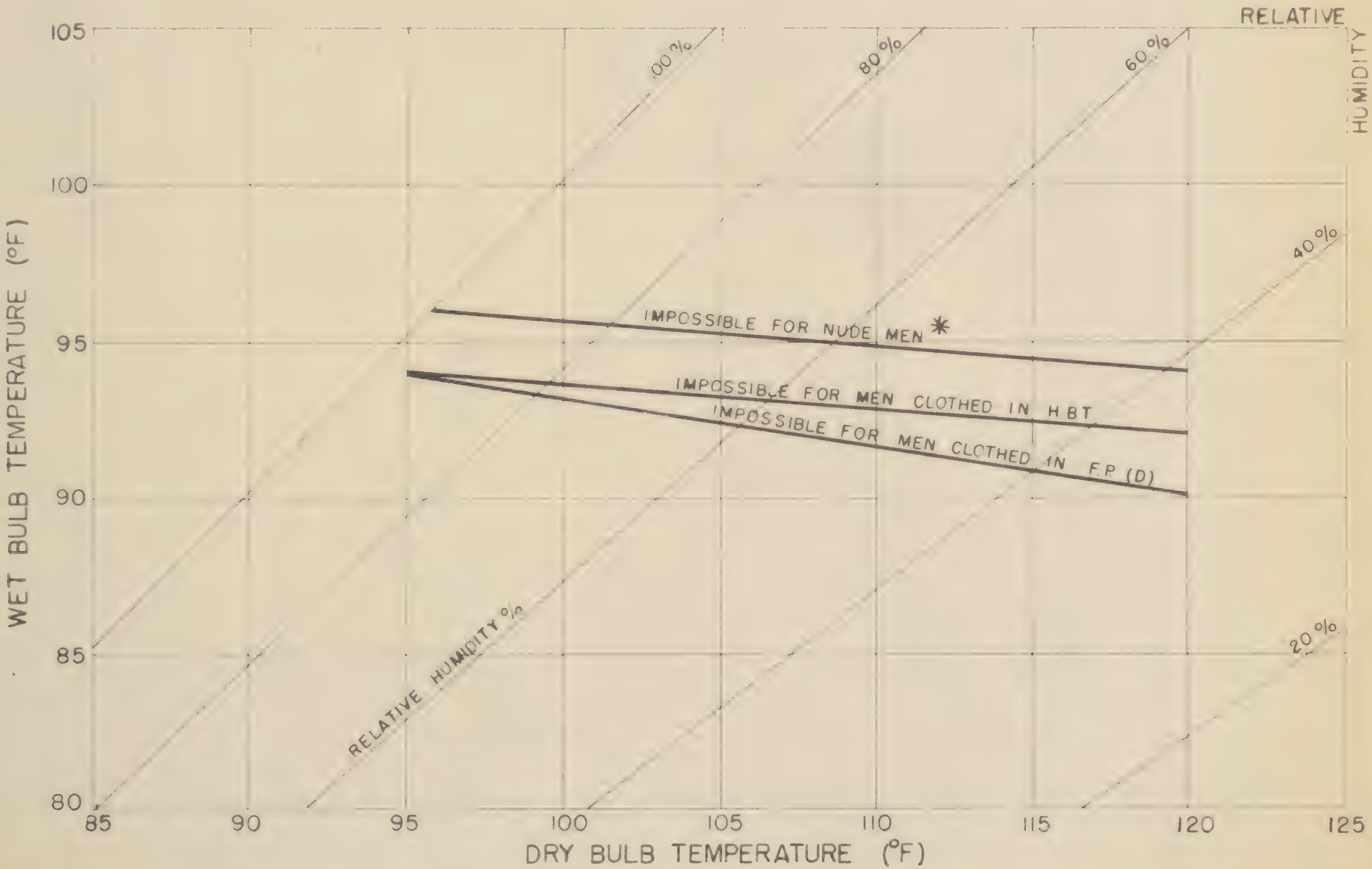
H.B.T. = HERRINGBONE TWILL SINGLE LAYER

F.P = FLAMEPROOFED TWILL SINGLE LAYER

CHART 7

THRESHOLD ENVIRONMENTAL LIMITS

MEN CANNOT WALK FOR FOUR CONTINUOUS HOURS
AT OR ABOVE ENVIRONMENTS DESIGNATED



H.B.T. = HERRINGBONE TWILL SINGLE LAYER
F.P. (D) = FLAMEPROOFED TWILL SINGLE LAYER

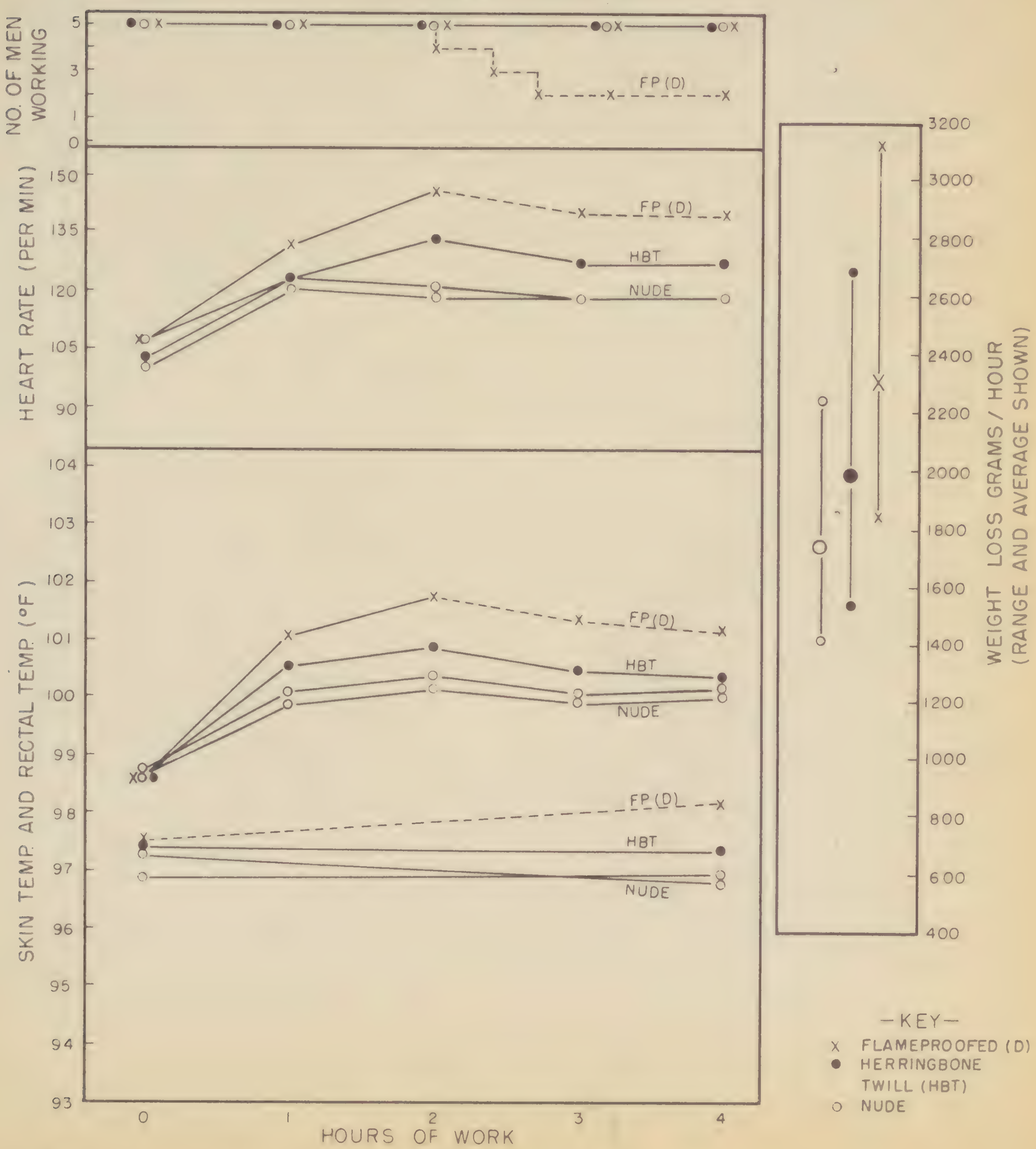
* ESTABLISHED BY PREVIOUS STUDY

CONFIDENTIAL

CHART 8

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D. B. 120° F. - W. B. 90° F.

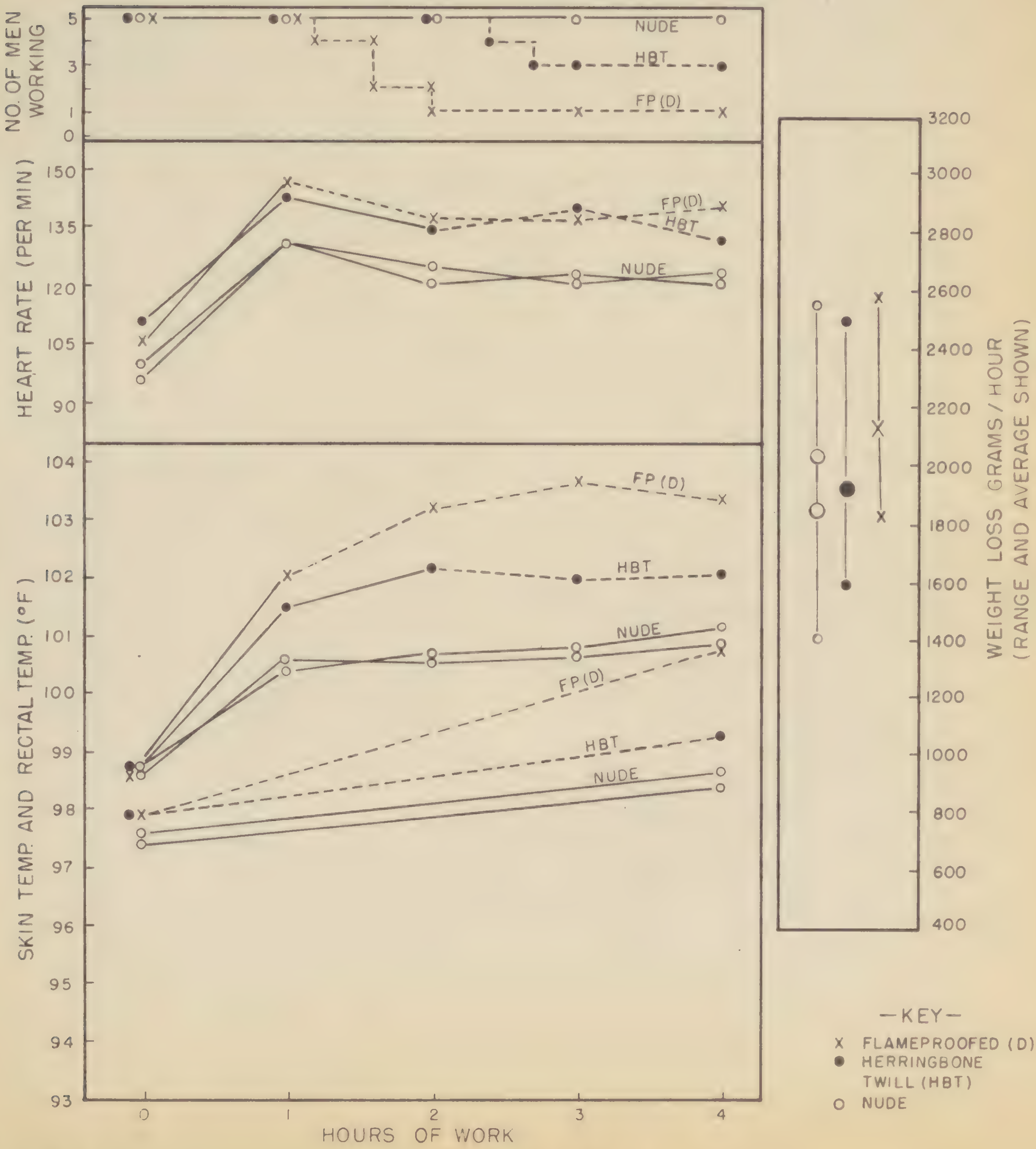


Incl. #3

CHART 9

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D. B. 120° F. - W.B. 92° F.

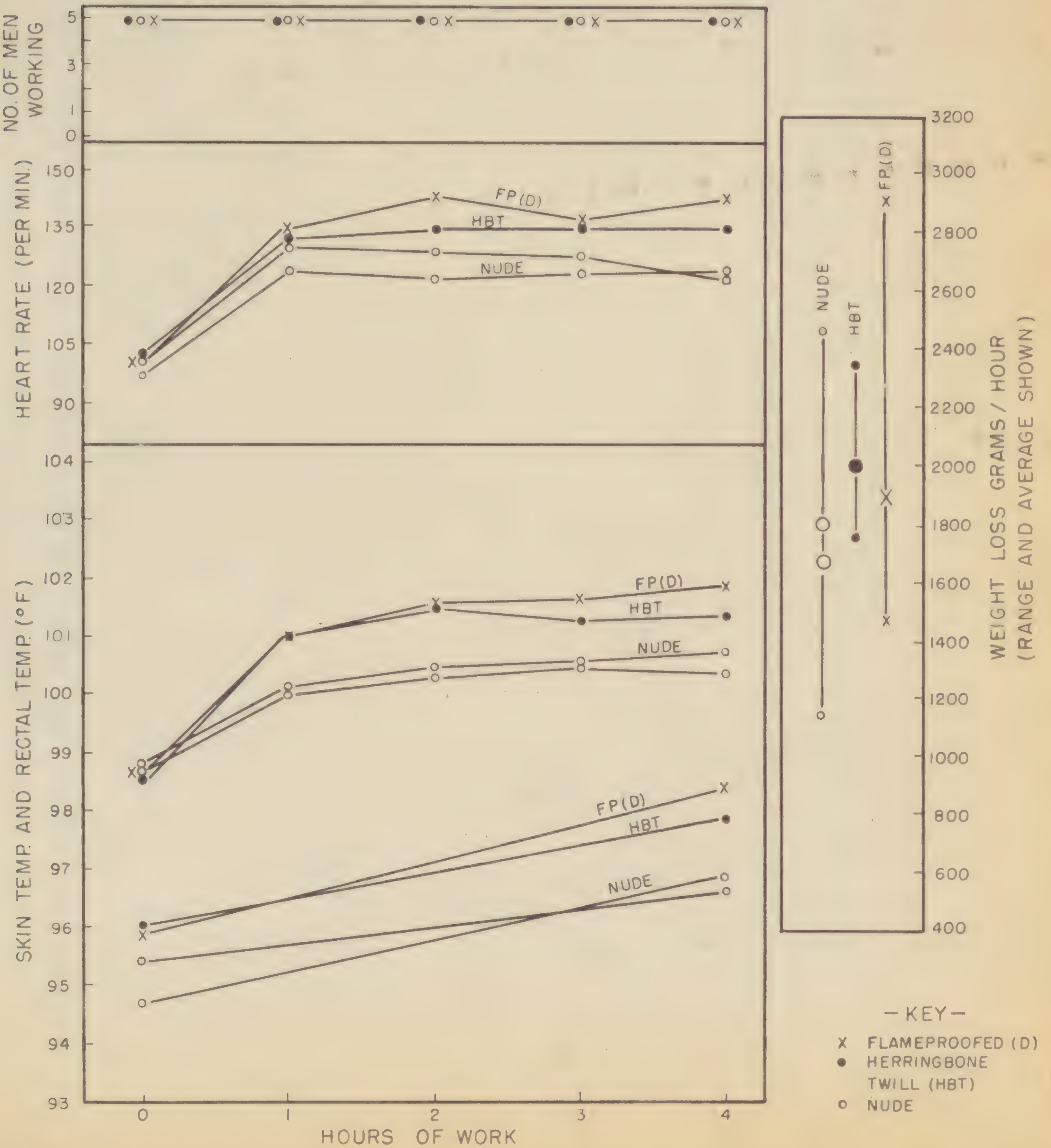


Incl #2

CHART 10

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D.B. 93° F. - W.B. 92° F.

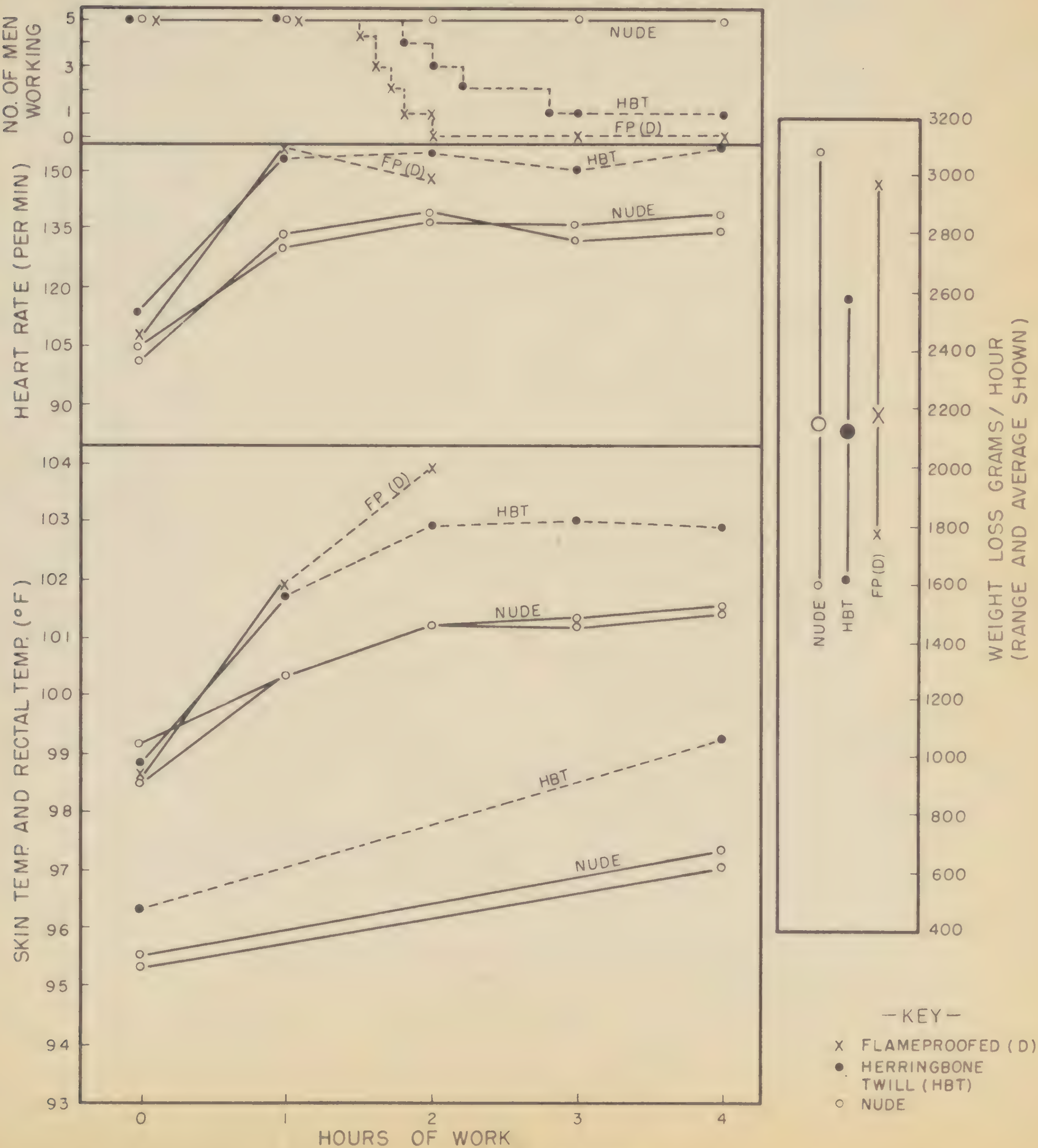


Incl. #3

CHART II

AVERAGE PHYSIOLOGIC RESPONSE OF WORKING MEN WEARING FLAMEPROOFED TWILL AND HERRINGBONE TWILL

D.B. 95° F.- W.B. 94° F.



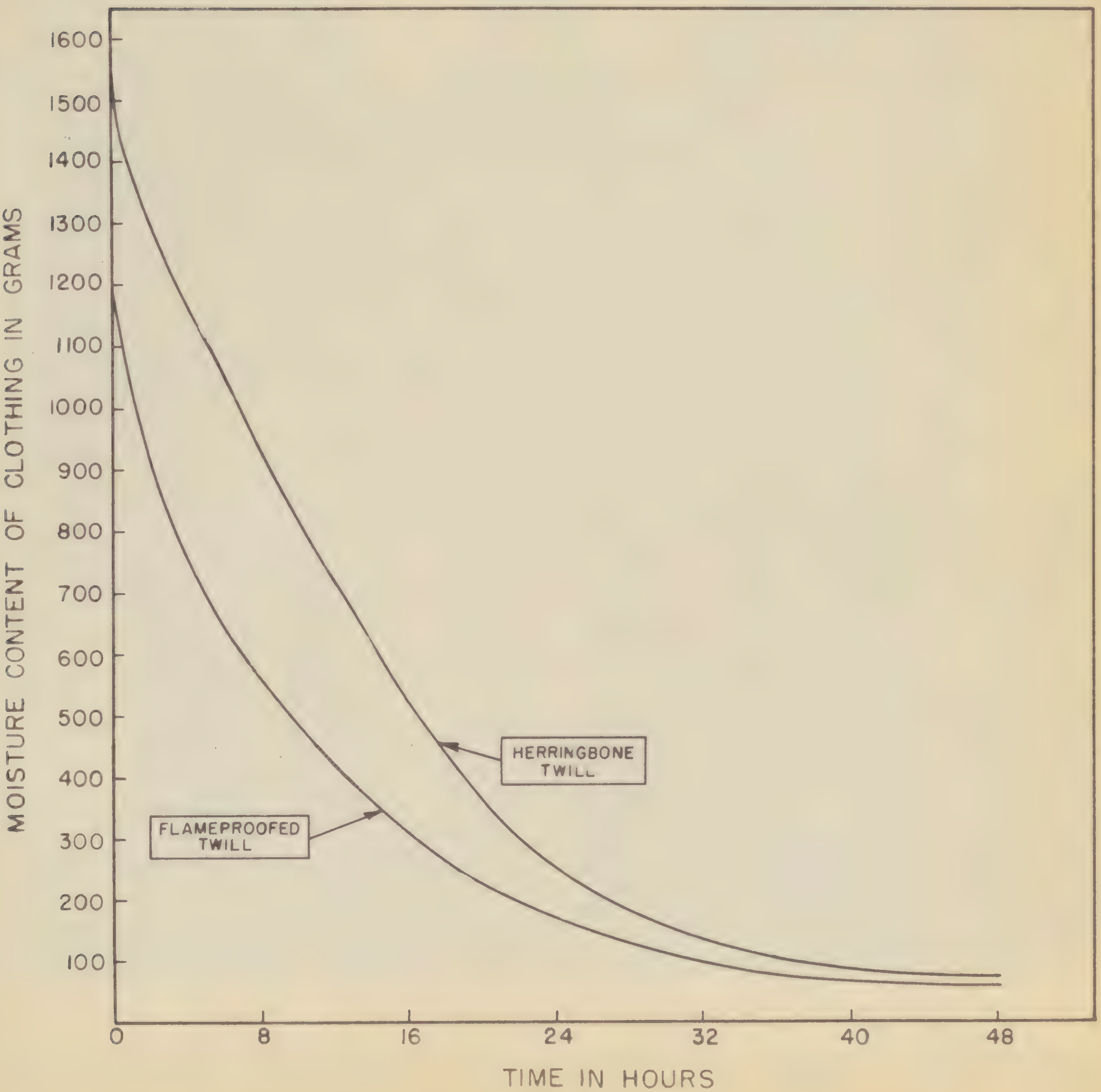
Incl F3

CHART 12

THE DRYING RATE OF FLAMEPROOFED AND HERRINGBONE TWILL UNIFORMS AFTER IMMERSION IN 72° WATER FOR 45 HOURS

DRYING CHAMBER: D.B. 72° F., W.B. 65° F.

DATA FROM ONE SET OF CLOTHING



INITIAL DRY WEIGHT FOR H.B.T. = 1383 GRAMS
INITIAL DRY WEIGHT FOR F.P. = 2011 GRAMS

Incl. #3

HBT HBT FPT "D"

The sweat uptake of herringbone twill and flameproofed twill garments on first wearing. The new herringbone twill garment in the center is worn by a subject who did not walk.

ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KY.

Project No. T-5

Photograph #1

incl #4

HBT FPT "D"

Appearance of herringbone twill garment during twelfth wearing compared with that of flameproof twill during fifth wearing.

ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KY.

Project T-5

Photograph # 2

Incl #4